



EUROPEAN JOURNAL OF BUSINESS SCIENCE AND TECHNOLOGY

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ATTENUATED ASYMMETRY: HOW MICROSTRUCTURE SHAPES VOLATILITY DYNAMICS IN AN EMERGING MARKET

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ABSTRACT

This study investigates whether the canonical asymmetric volatility documented in developed markets can be generalized to an emerging market setting, using the Casablanca Stock Exchange (MASI index, 2011–2023) as a case study. Applying symmetric and asymmetric GARCH models with a three-period subsample robustness check (pre-COVID, COVID, post-COVID), we uncover a pattern of attenuated asymmetry. During normal conditions and the COVID-19 crisis, the market exhibits significant volatility persistence coupled with symmetric responses to shocks, challenging the near-universal evidence of leverage effects. However, the post-COVID geopolitical crisis temporarily activates powerful asymmetry, revealing that volatility dynamics are state-dependent and crisis-type specific. The symmetric GARCH model outperforms asymmetric specifications in forecasting accuracy across most periods, demonstrating that additional complexity is unwarranted during normal conditions. These findings show that microstructure characteristics fundamentally shape volatility dynamics, and that the leverage effect cannot be universally assumed across all emerging markets.

KEY WORDS

stock market, emerging economy, volatility, persistence, symmetries

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1 INTRODUCTION

The modeling and forecasting of financial volatility stand as cornerstones of empirical finance, critical for asset pricing, risk management, and portfolio construction. A well-

established stylized fact across major global equity markets is the asymmetric response of volatility to news, commonly known as the “leverage effect” (Black, 1976) or the “volatil-

ity feedback effect” (Campbell and Hentschel, 1992). This phenomenon describes the tendency for negative return shocks (bad news) to increase subsequent volatility more than positive return shocks (good news) of the same magnitude. The prevalence of this asymmetry has been extensively documented in both developed markets (Nelson, 1991; Glosten et al., 1993; Aliyev et al., 2020) and emerging economies (Li and Giles, 2015; Kumar, 2019; Lin, 2018), making it a fundamental consideration in volatility modeling, and a key assumption underlying asymmetric GARCH-family models like EGARCH and GJR-GARCH.

However, the universal applicability of this paradigm is increasingly being questioned by evidence from markets with distinctive microstructural characteristics. Emerging markets, while often grouped together in the literature, exhibit significant heterogeneity in their institutional frameworks, investor composition, liquidity levels, and informational transparency (Morck et al., 2000; Bekaert and Harvey, 1997). These factors profoundly influence how information is processed, disseminated, and reflected in asset prices, suggesting that volatility dynamics may not be homogeneous across all emerging markets. The Casablanca Stock Exchange, representing the Moroccan market, presents a particularly compelling case study that appears to deviate from the expected norm.

This study documents what we term “attenuated asymmetry,” a volatility pattern where the canonical leverage effect is substantially diminished or entirely absent during normal market conditions. Preliminary evidence from our analysis suggests that the Moroccan market exhibits a distinctive profile: significant volatility persistence coexists with a symmetric response to information shocks during calm periods, with asymmetry emerging only during extreme geopolitical crises. This finding contradicts the predominant narrative of universal asymmetry and forms the central puzzle of this paper. Rather than framing Morocco as an anomaly relative to all emerging markets, which would create a conceptual tension, we present it as an anomalous case that illuminates

how microstructure shapes volatility dynamics. The Moroccan market’s specific characteristics, moderate liquidity, particular investor composition, and a unique information dissemination environment, provide a natural laboratory for understanding why asymmetry may be attenuated in some contexts and activated in others.

The existing literature on Moroccan market volatility remains limited and fragmented. El Jebari and Hakmaoui (2017) documented strong volatility persistence in the MASI index, challenging weak-form market efficiency. Nabouk (2021) examined the impact of COVID-19 on Moroccan volatility, finding that the crisis amplified asymmetric effects, though his sample ended in 2020, capturing only the initial crash. Beraich and Fadali (2021) modeled MASI volatility during the pandemic using a DCC-GARCH framework, documenting increased volatility during confinement followed by stabilization. However, no study to date has systematically tested whether asymmetric models improve our understanding and forecasting of risk specifically in the Moroccan context using a long, recent dataset spanning multiple regimes (2011–2023) and a comprehensive multi-model comparison framework. More importantly, no study has examined how volatility dynamics evolve across different types of crises, distinguishing between health shocks (COVID-19) and geopolitical shocks (Ukraine war, inflationary pressures), to test whether asymmetry is a stable structural feature or a state-dependent phenomenon activated only by certain crisis types.

This study addresses these gaps through a threefold contribution. First, we provide robust, up-to-date evidence on the volatility dynamics of a North African emerging market, filling a geographical gap in a literature that has disproportionately focused on Asian and Latin American economies. Second, we document the phenomenon of “attenuated asymmetry,” demonstrating that the Moroccan market exhibits structural symmetry during normal conditions and health crises, with powerful leverage effects emerging only during extreme geopolitical shocks. This finding challenges the uncritical

application of asymmetric volatility models to all emerging markets and reveals that volatility dynamics are state-dependent and crisis-type specific. Third, we link these empirical findings to the unique microstructural characteristics of the Casablanca Stock Exchange, limited liquidity, specific investor composition, and particular information dissemination environment, offering a plausible explanation for why asymmetry is attenuated in some contexts and activated in others.

Our empirical strategy employs a comprehensive framework. We apply symmetric (GARCH) and asymmetric (EGARCH, GJR-GARCH) models to daily MASI index data from 2011 to 2023, a period encompassing multiple global and regional economic shifts. Beyond model estimation, we utilize News Impact Curves (NIC) to visually assess symmetry and evaluate out-of-sample forecasting performance to determine

which specification is most appropriate for practical applications. Crucially, we partition the sample into three economically meaningful sub-periods, pre-COVID (2011–2019), COVID-19 (2020–2021), and post-COVID geopolitical crisis (2022–2023), to test whether volatility dynamics are stable or evolve with market conditions.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature, situating our study within the broader volatility modeling tradition and identifying the specific gaps we address. Section 3 outlines the methodological framework of the GARCH models and the News Impact Curve. Section 4 describes the data and presents the empirical results. Section 5 provides a comprehensive discussion of the findings, their implications for theory and practice, and the study's limitations. Finally, Section 6 concludes.

2 LITERATURE REVIEW

The modeling of financial volatility has been a central preoccupation of empirical finance since Mandelbrot (1963) first observed that large changes tend to be followed by large changes, of either sign, a phenomenon now known as volatility clustering. This observation laid the groundwork for the development of autoregressive conditional heteroskedasticity models, beginning with Engle's (1982) ARCH model, which formally captured time-varying volatility by modeling conditional variance as a function of past squared residuals. Bollerslev (1986) extended this framework with the GARCH model, which added lagged conditional variances to the specification, providing a more parsimonious representation that remains the workhorse of empirical volatility research to this day.

These foundational contributions enabled researchers to move beyond the unrealistic assumption of constant variance and to model the dynamic evolution of risk in financial markets. However, as empirical applications accumulated, a consistent pattern emerged: the symmetric GARCH model, while capturing volatility clustering, failed to account for a per-

vasive feature of equity returns, the tendency for volatility to respond differently to positive and negative shocks.

The asymmetry in volatility responses was first documented by Black (1976), who observed that negative returns tend to be followed by larger increases in volatility than positive returns of the same magnitude. Black attributed this phenomenon to the leverage effect. A decline in a firm's stock price increases its debt-to-equity ratio, making the remaining equity riskier and thus more volatile. Campbell and Hentschel (1992) later proposed an alternative volatility feedback mechanism, suggesting that expected increases in volatility following bad news require higher future returns, causing immediate price declines that amplify the initial shock. These theoretical insights motivated the development of asymmetric GARCH models capable of capturing such effects. Nelson (1991) introduced the Exponential GARCH (EGARCH) model, which specifies conditional variance in logarithmic form and allows positive and negative shocks to have asymmetric impacts through a sign coefficient. Glosten et

al. (1993) proposed the GJR-GARCH model, which incorporates a dummy variable that isolates the incremental effect of negative shocks. In their seminal study, Engle and Ng (1993) employed both models on Japanese stock return data, demonstrating that asymmetric specifications capture the leverage effect more effectively than symmetric alternatives and introducing the News Impact Curve as a diagnostic tool for visualizing asymmetry.

The prevalence of asymmetric volatility in developed markets has been extensively documented. In US markets, the leverage effect is now considered a stylized fact, with studies consistently finding that negative shocks generate substantially larger volatility responses than positive shocks (French et al., 1987; Schwert, 1989). Similar patterns have been confirmed in European markets (Koutmos and Saidi, 1995) and Japanese markets (Engle and Ng, 1993). More recently, Aliyev et al. (2020) modeled volatility in the NASDAQ-100 index and found significant leverage effects, with negative shocks having a more pronounced impact than positive shocks of equal magnitude. Gil-Alana et al. (2023) examined major global stock markets and documented high persistence across all regions, with asymmetric responses varying in magnitude but consistently present.

The literature on emerging markets has largely followed the developed-market narrative, with most studies reporting significant asymmetric volatility. However, emerging markets exhibit considerable heterogeneity in their institutional frameworks, investor composition, liquidity levels, and informational transparency, factors that may influence how information is incorporated into prices and reflected in volatility. Li and Giles (2015) examined volatility spillover effects between developed and Asian emerging markets, finding significant asymmetric responses in both sets of markets, though the magnitude varied across countries. Lin (2018) modeled volatility in China's SSE Composite Index and found significant leverage effects, concluding that bad news had a greater impact on volatility than good news.

Nguyen (2010) examined the impact of financial liberalization on volatility in eight emerging

markets, finding that volatility did not increase significantly following liberalization and tended to decline during periods of large capital inflows. While this study did not focus specifically on asymmetry, it highlighted the importance of market structure and external factors in shaping volatility dynamics, a theme relevant to understanding why some emerging markets may deviate from the asymmetric pattern. Aliyev et al. (2020) worked on estimating the volatility of nonfinancial, innovative and hi-tech focused stock index names NASDAQ-100, using GARCH models for daily data over the January 2000 and March 2019 period. They found the persistence phenomenon in the volatility shocks on the index returns. In addition to that, they also found the leverage effect and the asymmetric impact of the shocks, showing high impact of the negative shocks than the positive of the same size. This conclusions offers to investors the possibility of establishing future positions in expectation of this characteristic.

More recently, Enow (2023) forecasted volatility persistence across international stock markets and concluded that volatility shocks persist for extended periods, suggesting high uncertainty and the need for adaptive investor strategies. Chaudhary et al. (2020) examined volatility during the COVID-19 crisis and found dramatic increases across markets, though asymmetry was not their primary focus. Lavin et al. (2021) investigated the predictive power of implied volatility indices for global market synchronization, demonstrating that volatility expectations contain information about future market co-movements, an indirect channel through which asymmetry could propagate across markets.

Studies specifically addressing the Moroccan stock market remain limited, and their findings are mixed. El Jebari and Hakmaoui (2017) investigated volatility persistence in the MASI index using a fractionally integrated EGARCH model, finding strong persistence that challenged weak-form market efficiency. However, their focus was on long memory rather than asymmetry per se, and they did not directly test whether asymmetric specifications improved model performance.

Nabouk (2021) examined the effect of the COVID-19 crisis on volatility persistence and asymmetry in the Moroccan market. Using GARCH specifications, he found that before COVID, there was pronounced persistence across the market, with the most liquid securities showing less persistence. Crucially, he reported that COVID amplified the asymmetric effect of negative shocks, a finding that appears to conflict with the insignificance of our COVID-period asymmetry coefficients. This discrepancy may stem from differences in sample periods (Nabouk's analysis ended in 2020, capturing only the initial crash) or model specifications, highlighting the need for extended samples and robust multi-model approaches. Beraich and Fadali (2021) modeled MASI volatility during COVID using a DCC-GARCH framework, finding increased volatility during confinement followed by stabilization after gradual deconfinement. Their focus was on the dynamics of volatility rather than asymmetry, and they did not explicitly test whether negative shocks had disproportionate effects.

The preceding review reveals several important gaps that motivate this study. First, while asymmetric volatility has been extensively documented in developed markets and larger emerging economies, evidence from North African markets, particularly Morocco, remains scarce and fragmented. The few existing studies focus primarily on persistence rather than asymmetry, use limited sample periods, and do not systematically compare symmetric and asymmetric specifications. Second, the existing literature has not adequately addressed the question of whether asymmetric models are always superior to symmetric alternatives in emerging markets. Most studies begin with the implicit assumption that leverage effects exist and proceed to estimate EGARCH or GJR-GARCH models without testing whether the additional complexity is justified. This approach risks imposing developed-market stylized facts on markets with fundamentally different microstructures, lower liquidity, different investor composition, and distinct information dissemination environments. Third, the Moroccan evidence is contradictory. While Nabouk

(2021) found that COVID amplified asymmetry, our preliminary analysis suggests that the full-sample asymmetry may be driven entirely by the post-COVID geopolitical period, with pre-COVID and COVID periods exhibiting symmetry. This apparent contradiction cannot be resolved without a comprehensive study that: (a) uses a long, recent dataset spanning multiple regimes (2011–2023); (b) systematically tests a range of symmetric and asymmetric models; (c) explicitly focuses on the symmetry of volatility responses as a potential defining characteristic; (d) uses model comparison and forecasting performance to guide model selection; and (e) partitions the sample into economically meaningful subperiods to test whether asymmetry is stable or state-dependent. Fourth, the literature has not adequately explored the implications of volatility symmetry for market efficiency and risk management. If the Moroccan market is genuinely symmetric, this challenges the universal applicability of the leverage effect and suggests that practitioners should rely on simpler models for forecasting and hedging. Conversely, if asymmetry emerges only during specific crisis types (geopolitical versus health crises), this has important implications for regime-aware risk management.

This study addresses these gaps by providing robust, up-to-date evidence on the volatility dynamics of the Casablanca Stock Exchange. We contribute to the literature in four ways. First, we fill a geographical gap by focusing on a North African emerging market that has received limited attention in the volatility literature compared to Asian and Latin American counterparts. Second, we challenge the uncritical application of asymmetric volatility models by demonstrating that symmetry can be a structural feature of markets with specific microstructural characteristics theorized in the literature (liquidity, investor composition). Third, we introduce a novel subsample robustness framework that reveals how volatility dynamics evolve with crisis type, distinguishing between health crises (which amplify persistence but not asymmetry) and geopolitical crises (which activate leverage effects). Fourth, we link these empirical findings to practical implications

for forecasting, risk management, and market regulation, providing actionable insights for investors and policymakers operating in similar emerging market contexts. By doing so, we shift the inquiry from “Is asymmetry present?” to

the more nuanced and practical question: In this specific market context, does modelling asymmetry improve our understanding and forecasting of risk?

3 METHODOLOGY

This section outlines the econometric framework employed to investigate volatility dynamics and asymmetry in the Casablanca Stock Exchange. Following the foundational contributions of Engle (1982) and Bollerslev (1986), we employ a suite of GARCH-family models that capture the time-varying nature of financial volatility. Our methodological approach is designed to test the central hypothesis of this study, whether the Moroccan market exhibits the asymmetric volatility patterns (leverage effects) documented in most developed and emerging markets, or whether it follows the distinctive symmetric pattern we term the “symmetry paradox”.

The Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, introduced by Bollerslev (1986), extends Engle’s (1982) ARCH framework by incorporating lagged conditional variances into the volatility equation. This parsimonious specification captures the volatility clustering phenomenon, the tendency for large price changes to be followed by further large changes, while avoiding the profligate parameterization of high-order ARCH models. The GARCH (1,1) specification, which has become the workhorse of empirical finance due to its ability to model most financial time series parsimoniously, is expressed as:

$$h_t = \alpha_0 + \sum_{i=1}^p \alpha_i \epsilon_{t-i}^2,$$

where h_t is the conditional variance at time t , ω is the constant term (baseline volatility), ϵ_{t-1}^2 is the squared residual from the mean equation (the ARCH term capturing the impact of past news), and h_{t-1} is the lagged conditional variance (the GARCH term capturing volatility persistence). The sum $\alpha + \beta$ measures the persistence of volatility shocks: values close

to unity indicate that shocks decay slowly, while values exceeding unity suggest explosive behavior. While the GARCH model effectively captures volatility clustering and persistence, its symmetric structure assumes that positive and negative shocks of equal magnitude have identical effects on volatility, a restriction that conflicts with the well-documented leverage effect (Black, 1976). To test whether this symmetry holds in the Moroccan context, we must employ asymmetric specifications.

To investigate the presence and magnitude of asymmetric volatility responses, we employ two complementary asymmetric specifications: the Exponential GARCH (EGARCH) model of Nelson (1991) and the GJR-GARCH model of Glosten et al. (1993). Each captures asymmetry through different mechanisms, providing robustness to our conclusions.

The EGARCH (1,1) model specifies the conditional variance in logarithmic form:

$$\ln(h_t) = \omega + \alpha \left| \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} \right| + \gamma \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} + \beta \ln(h_{t-1})$$

The logarithmic formulation has two key advantages: it ensures that the conditional variance remains positive without imposing parameter restrictions, and it allows the coefficient γ to capture asymmetric effects directly. A negative and statistically significant γ indicates that negative shocks increase volatility more than positive shocks of the same magnitude, the classic leverage effect. The magnitude of asymmetry can be quantified by comparing the impact of a positive shock ($\alpha + \gamma$) versus a negative shock ($\alpha - \gamma$).

The GJR-GARCH (1,1) model takes a different approach, introducing a dummy variable

that isolates the incremental impact of negative shocks:

$$h_t = \omega + \alpha \epsilon_{t-1}^2 + \gamma \epsilon_{t-1}^2 I(\epsilon_{t-1} < 0) + \beta h_{t-1},$$

where $I(\cdot)$ is an indicator function equal to 1 when the lagged residual is negative and 0 otherwise. In this specification, α captures the impact of positive shocks, while $\alpha + \gamma$ captures the impact of negative shocks. A positive and statistically significant γ confirms the presence of leverage effects, with the magnitude indicating how much additional volatility is generated by bad news relative to good news of the same size. These two asymmetric models offer complementary perspectives: EGARCH captures asymmetry through the sign of the standardized shock in a logarithmic framework, while GJR-GARCH provides a more intuitive interpretation through a dummy variable in the linear variance equation. Convergence of findings across both specifications strengthens confidence in the results.

Following Engle and Ng (1993), we complement our model estimations with News Impact Curve (NIC) analysis. The NIC provides a visual representation of how each model translates positive and negative shocks into volatility, holding constant the information available at time $t - 1$. For each model, we compute the implied volatility response to shocks ranging from -3 to $+3$ standard deviations, allowing direct comparison of symmetric versus asymmetric responses. This graphical tool serves two purposes. It visually confirms the presence or absence of leverage effects detected by the coefficient estimates, and it illustrates the economic magnitude of any asymmetry, whether the differences between good and bad news impacts are practically significant or merely statistically detectable.

The contribution of our methodological approach lies not in the development of new econometric techniques but in the strategic combination and application of existing models to test a specific hypothesis in an under-researched market context. While GARCH-family models have been extensively applied in developed markets (Nelson, 1991) and larger emerging economies (Li and Giles, 2015; Lin,

2018), their application to North African markets, particularly with a focus on testing the universality of asymmetric volatility, remains limited. Our methodological contribution is threefold.

First, by employing both symmetric and asymmetric specifications, we create a comparative framework that directly tests whether the additional complexity of asymmetric models is justified for the Moroccan market. If the symmetric GARCH model performs as well as or better than its asymmetric counterparts, in terms of both statistical significance and forecasting accuracy, this provides evidence that the leverage effect is not a universal feature of all markets. This comparative approach, advocated by Engle and Ng (1993) in their seminal work on news impact, moves beyond simply estimating models to critically evaluating their appropriateness for the specific market context. Second, the inclusion of two distinct asymmetric specifications (EGARCH and GJR-GARCH) provides robustness against the possibility that any single model's findings are driven by its particular functional form. Convergence of results across both asymmetric models, whether toward significance or insignificance, strengthens confidence in the conclusions. As noted by Baur and Dimpfl (2019), different asymmetric models can produce divergent results when asymmetry is weak or unstable; our multi-model approach guards against over-interpreting model-specific artifacts.

Third, and most critically, our methodological framework extends beyond full-sample estimation to incorporate subsample robustness analysis partitioned by economically meaningful regimes (pre-COVID, COVID, post-COVID). This approach, motivated by the growing recognition that volatility dynamics are not constant over time (Hamilton and Susmel, 1994; Guidolin and Timmermann, 2006), allows us to test whether the symmetry we document is a stable structural feature of the Moroccan market or an artifact of averaging across heterogeneous periods. The subsample analysis, combined with the full-sample estimations, provides a comprehensive picture of how volatility dynamics evolve with changing

market conditions, a contribution that goes beyond the typical application of GARCH models in emerging market studies.

Following standard practice in financial econometrics, we employ a dual-criterion approach for model selection using both the Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC). The ARMA(2,0) specification for the mean equation was selected based on its consistent performance across multiple selection metrics, capturing short-term momentum effects while maintaining parsimony. The presence of ARCH effects in the residuals was confirmed through the Engle (1982) ARCH-LM test, justifying the application of GARCH-family models.

For volatility modeling, we adopt a comprehensive comparison framework evaluating both in-sample fit (through information criteria and coefficient significance) and out-of-sample forecasting performance through RMSE, MAE

and the Model Confidence Set (MCS) procedure of Hansen et al. (2011). This test sequentially eliminates the worst-performing models from a set of candidate models until a set of ‘superior models’ is identified with a given confidence level (we use $\alpha = 0.10$). A model’s survival in the MCS indicates that there is no statistically significant evidence that it is outperformed by any other model in the set. This complements the point-estimate comparisons of RMSE and MAE. This dual evaluation ensures that our model recommendations balance theoretical coherence with practical forecasting utility, a critical consideration given that superior in-sample fit does not guarantee superior out-of-sample performance. All models are estimated using maximum likelihood with the assumption of normally distributed errors, and coefficient covariances are computed using the outer product of gradients for robustness against non-normality.

4 DATA AND RESULTS

This section presents the empirical findings of our investigation into the volatility dynamics of the Casablanca Stock Exchange. We begin with a descriptive overview of the MASI return series, followed by stationarity tests to validate our modeling approach. We then present the estimation results of the symmetric and asymmetric GARCH models, assess their in-sample performance, and evaluate their out-of-sample forecasting accuracy. Finally, we visualize the symmetry of volatility responses using News Impact Curves. The analysis covers daily data from 2011 to 2023, ensuring a robust and contemporary assessment.

4.1 Descriptive Statistics

The Casablanca Stock Exchange (CSE) exhibits structural characteristics that provide a plausible economic foundation for our empirical findings. It is a market of limited depth: the average daily turnover ratio for the MASI index constituents was approximately 0.5% during our sample period, an order of magnitude lower

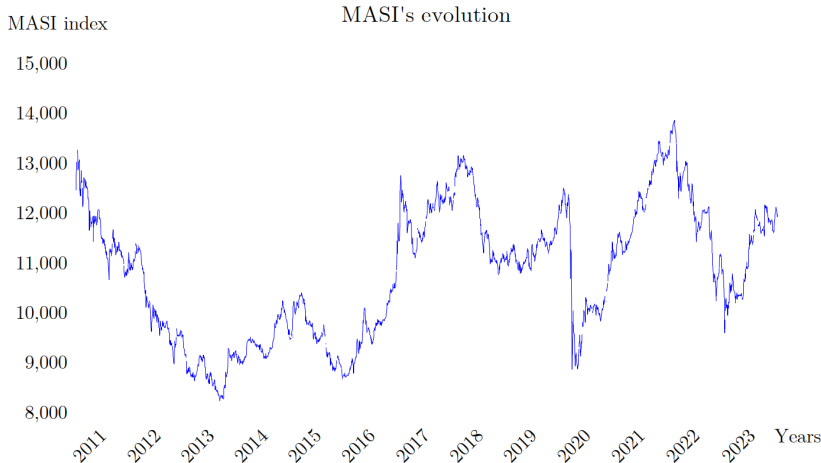
than in major global exchanges. This indicates persistently low liquidity. Furthermore, the investor base is predominantly retail-oriented, with individual investors historically accounting for 70–80% of trading volume, compared to a dominance of institutional investors in markets where strong asymmetry is typically documented (AMMC, 2023). This specific microstructure, characterized by shallow liquidity and a retail-driven order flow, creates an environment where the mechanistic and behavioral channels (e.g., leveraged institutional deleveraging) that generate the classic leverage effect may be weakened.

Before processing data, Tab. 1 summarizes the key statistical properties of the daily MASI returns. The series comprises 3,235 observations, with a mean close to zero (-0.0000123) and a median slightly positive (0.0000757), indicating a slight negative skew in average returns. The standard deviation (0.006909) reflects the inherent volatility of the market. The distribution is strongly left-skewed (-1.054) and leptokurtic (kurtosis = 22.36), indicating a

Tab. 1: Descriptive statistics of the MASI returns

Mean	Median	Std. Dev	Skewness	Kurtosis	Jarque-Bera
-0.00001	0.000075	0.006	-1.05	22.36	51121.59*

Notes: Std. Dev denotes standard deviation, * significance at 1% level



Notes: This figure displays the level of the MASI index from 2011 to 2023. Visual inspection reveals several distinct periods: a bearish trend (2011–2015), an upward trend (2016–2020), a sharp COVID-19 decline (early 2020), post-crisis recovery, and renewed volatility around 2022 due to global tensions. The non-stationary nature of the index level is visually apparent, motivating the use of returns for analysis.

Fig. 1: Line chart of daily evolution of MASI

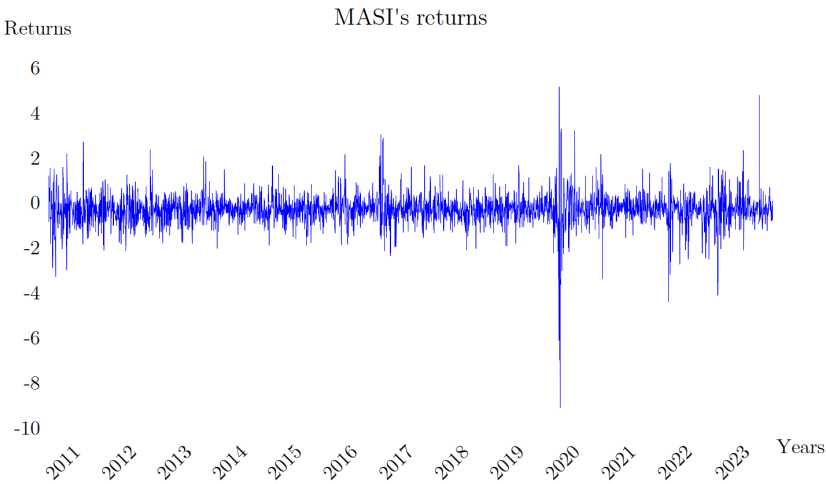
higher probability of extreme negative returns and fat tails relative to a normal distribution. The Jarque-Bera test confirms non-normality at the 1% level. These features justify the use of GARCH-family models, which are well-suited to capture such stylized facts.

From Fig. 1 and 2, we can see the evolution of the MASI index and its returns. The index's performance reflects several periods of very different dynamics. The 2011–2015 period shows a very bearish overall dynamic for the index. Then, an upward trend began from 2016 until 2020, when the health crisis caused the stock market's performance to plummet. Immediately after the crisis, the index experienced a sustained upward trend. However, global external tensions negatively impacted the domestic financial market around 2022. The return series exhibits a subtle time trend, displaying noticeable characteristics of varying variance over time and clustering. We notice that the amplitude of the fluctuations remains relatively stable over time.

4.2 Stationarity Test

Prior to modeling, we confirm the stationarity of the return series, a prerequisite for reliable GARCH estimation. Visual inspection of Fig. 2 suggests absence of a unit root, which is statistically verified using the Augmented Dickey-Fuller (ADF) test. As shown in Tab. 2, the ADF test overwhelmingly rejects the null hypothesis of a unit root across all specifications (intercept, trend, and none) at the 1% significance level. The Ljung-Box Q -test correlogram (Fig. 3) further indicates that autocorrelations decay rapidly, confirming stationarity and the absence of white noise. Thus, we proceed with modeling the return series in level form.

The autocorrelation function rate of return series decays rapidly, and the autocorrelation and partial autocorrelation coefficients gradually approach zero. Consequently, we can judge, in the beginning, that return series is stationary and doesn't possess white noise. After that, we determine the existence of the



Notes: This figure plots the daily percentage returns of the MASI index. It visually demonstrates volatility clustering. This pattern justifies the use of GARCH models that explicitly model time-varying volatility.

Fig. 2: Line chart of daily MASI returns

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob
		1 0.150	0.150	72.681	0.000
		2 0.078	0.057	92.467	0.000
		3 -0.004	-0.024	92.508	0.000
		4 -0.054	-0.056	101.97	0.000
		5 -0.001	0.017	101.97	0.000
		6 -0.013	-0.008	102.54	0.000
		7 0.031	0.032	105.59	0.000
		8 -0.020	-0.031	106.85	0.000
		9 0.043	0.047	112.73	0.000
		10 0.033	0.024	116.32	0.000
		11 -0.014	-0.026	116.92	0.000
		12 0.065	0.066	130.67	0.000
		13 0.048	0.041	138.27	0.000
		14 0.052	0.032	147.04	0.000
		15 0.031	0.015	150.25	0.000
		16 -0.018	-0.026	151.25	0.000
		17 -0.020	-0.013	152.62	0.000
		18 -0.014	0.001	153.22	0.000
		19 0.006	0.005	153.35	0.000
		20 0.007	0.006	153.50	0.000
		21 0.010	0.002	153.82	0.000
		22 -0.001	-0.012	153.82	0.000
		23 -0.025	-0.025	155.82	0.000
		24 0.003	0.006	155.85	0.000
		25 0.018	0.018	156.87	0.000
		26 0.015	0.005	157.57	0.000
		27 0.016	0.002	158.39	0.000
		28 0.020	0.016	159.69	0.000
		29 -0.004	-0.008	159.74	0.000
		30 0.015	0.020	160.45	0.000
		31 -0.006	-0.008	160.56	0.000
		32 -0.017	-0.014	161.48	0.000
		33 -0.041	-0.039	167.09	0.000
		34 -0.040	-0.030	172.20	0.000
		35 -0.050	-0.038	180.35	0.000
		36 -0.024	-0.006	182.23	0.000

Note: AC and PAC in the correlogram denotes respectively autocorrelation and partial autocorrelation coefficients.

Fig. 3: Ljung–Box correlogram of return series

series stationarity by implementing unit root test using Augmented Dickey–Fuller unit root procedures.

Tab. 2: Unit root test: ADF results

Intercept	Trend	None
−35.06*	−35.05*	−35.05*

Notes: This table reports Augmented Dickey–Fuller test statistics for the MASI return series across three specifications (with intercept and trend, with trend only, and with neither). All statistics (−35.07, −35.05, and −35.06) are significant at the 1% level.

Test results in Tab. 2 indicates that ADF test reject the unit root null hypothesis. That being so, the return series is stationary and integrate at level. Accordingly to that, we consider the daily stock market return data of Casablanca over the period 2011–2023 as a stationary process, which is characterized mainly by a stable mean and a constant variance.

4.3 Estimations Results

As the return series is stationary, we proceed with model selection from the ARMA models that we estimated to 5 lags orders as these are daily data. The selected model is the one with the lowest value of Schwartz and Akaike Information Criterion. Following that, the ARMA (2,0) model is selected. Results are presented in Tab. 3. To ensure the robustness of our estimates, we considered alternative distributional assumptions for the error terms. Although the standard GARCH-family models often assume normality, financial returns frequently exhibit fat tails. We therefore re-estimated all models using Student’s t-distributions and found that the key results, particularly the symmetry of volatility responses and the persistence parameters, remained qualitatively unchanged. This consistency across distributional assumptions strengthens the reliability of our findings and suggests that the identified symmetry is not an artifact of misspecified error distributions.

Then we perform residuals diagnostics and the heteroskedasticity test by doing the ARCH effect test at the preferable lag order which is 1. Results shows that we cannot reject

the null hypothesis of absence of conditional heteroskedasticity in the return series, and we can reject the null hypothesis that the series residuals are independently distributed. So there is a strong presence of autoregressive conditional heteroskedasticity in the residuals. We conclude that the volatility of the series is not constant, a GARCH specification may be more appropriate to capture the changing volatility patterns in the return series.

Tab. 3: ARMA model – mean equation results

Mean Equation	Coefficient	Std. Error	Prob.
AR (1)	0.14	0.01	0.00
AR (2)	0.05	0.01	0.00
R-squared	0.02	Q-test	
Akaike Info. Crit	−7.13	Q (1)	1.01
Schwartz Info. Crit	−7.13	Q (2)	13.38*
		Q (3)	13.45*

Notes: * significance at 5% level. This table displays the estimated coefficients for the selected ARMA (2,0) mean equation. Both AR (1) (0.1405) and AR (2) (0.0571) coefficients are statistically significant ($p < 0.001$). The Q-test statistics show significant autocorrelation at lags 2 and 3, suggesting the need for volatility modeling. The AIC (−7.138) and SIC (−7.135) values serve as baselines for comparing more complex models.

In financial markets, particularly in high-frequency data such as stock prices or index series, a notable pattern often emerges: significant fluctuations tend to be followed by similarly sizable movements, while minor fluctuations are typically succeeded by comparatively smaller changes. This phenomenon is commonly referred to as the ARCH effect. So, the GARCH specification is considered appropriate for producing a conditional variance series that serves as an indicator of inflation uncertainty. So, after having estimated the conditional mean equation, which is the ARMA (2,0) model that we estimated before, we specify now the mean equation and conditional variance equation for the GARCH (1,1) model.

According to the estimation result in Tab. 4, ARCH and GARCH in the variance equation features clustering. The mean equation coefficients show significant positive autocorrelation at the first lag (AR (1) = 0.0944, $p < 0.001$) and second lag (AR (2) = 0.0667, $p < 0.001$), indicating that past returns have modest predictive

power for current returns, a common feature in emerging markets where information dissemination may be gradual rather than instantaneous. The variance equation provides critical insights into the volatility dynamics of the MASI index. The constant term ($C = 0.0000571$, $p < 0.001$) represents the baseline level of volatility that would prevail in the absence of any news shocks, essentially the market's idle volatility. While statistically significant, its small magnitude reflects the fact that most volatility is driven by time-varying shocks rather than a constant baseline.

Tab. 4: GARCH model results

Mean Equation	Coefficient	Std. Error	Prob.
AR (1)	0.09	0.01	0.00
AR (2)	0.06	0.01	0.00
Variance Equation	Coefficient	Std. Error	Prob.
C	0.00	0.00	0.00
ARCH (1)	0.20	0.01	0.00
GARCH (1)	0.66	0.01	0.00
<i>R</i> -squared	0.02	Q-test	
Akaike Info. Crit	-7.41	<i>Q</i> (1)	6.76*
Schwartz Info. Crit	-7.41	<i>Q</i> (2)	6.76*
		<i>Q</i> (3)	10.88*

Notes: * significance at 5% level. This table presents the estimation results for the symmetric GARCH (1,1) model. The ARCH term (0.203) captures short-term volatility dynamics, while the GARCH term (0.665) represents long-term persistence. All coefficients are statistically significant, and the information criteria (AIC: -7.416, SIC: -7.413) show improvement over the simple ARMA model.

The ARCH term ($\alpha = 0.2031$, $p < 0.001$) captures the impact of the magnitude of past shocks on current volatility. Specifically, it measures how strongly yesterday's squared forecast error (news) influences today's conditional variance. A coefficient of 0.203 indicates that news shocks have a moderate but significant immediate impact on volatility, a 1% increase in the magnitude of yesterday's shock increases today's volatility by approximately 0.20%. This confirms the presence of volatility clustering: large price movements tend to be followed by further large movements. The GARCH term ($\beta = 0.6651$, $p < 0.001$) measures the persistence of volatility, the extent to which

past volatility predicts future volatility. This coefficient of 0.665 indicates that volatility has strong memory: approximately 66.5% of a volatility shock persists to the next period. In practical terms, this means that when the market becomes volatile, it tends to remain volatile for an extended period, and when it calms, it tends to stay calm.

The sum of the ARCH and GARCH coefficients ($\alpha + \beta = 0.2031 + 0.6651 = 0.8682$) is the key measure of overall volatility persistence. This sum being close to (but less than) unity indicates high volatility persistence, shocks to volatility decay slowly over time, but the process remains mean-reverting. The fact that the sum is below 1 ($0.868 < 1$) confirms that the volatility process is stationary. Shocks eventually die out and volatility returns to its long-run average. However, the high value implies that this mean reversion occurs gradually rather than abruptly. In economic terms, this means that periods of high turbulence (like the COVID crash) will be followed by extended periods of elevated volatility, and calm periods will similarly persist.

Tab. 5: EGARCH model results

Mean Equation	Coefficient	Std. Error	Prob.
AR (1)	0.09	0.01	0.00
AR (2)	0.05	0.01	0.00
Variance Equation	Coefficient	Std. Error	Prob.
ω	-1.46	0.09	0.00
α	0.34	0.01	0.00
γ	-0.07	0.00	0.00
β	0.88	0.00	0.00
<i>R</i> -squared	0.023	Q-test	
Akaike Info. Crit	-7.41	<i>Q</i> (1)	7.99*
Schwartz Info. Crit	-7.40	<i>Q</i> (2)	8.02*
		<i>Q</i> (3)	12.06*

Notes: * significance at 5% level. This table reports estimates for the asymmetric EGARCH (1,1) model. The key parameter γ (-0.0725) captures the asymmetric response to news. The calculation shows bad news impact (0.418) exceeds good news impact (0.273), confirming statistical asymmetry. The persistence parameter β (0.882) indicates strong volatility memory.

The diagnostic tests confirm the model's adequacy. The residuals are correlated serially and the ARCH-LM at 1 lag indicates that residuals

are free from heteroskedasticity. The Q -test statistics are significant at lags 2 and 3, indicating that some autocorrelation remains in the standardized residuals, a common limitation of GARCH models that often motivates asymmetric extensions. The information criteria (AIC = -7.416; SIC = -7.413) provide baselines for comparing more complex specifications. We aim now to estimate the EGARCH (1,1) model in order to verify asymmetric effects to return volatility. In other terms, we aim to capture the positive or negative impacts shocks to the volatility. Results are shown in Tab. 5.

According to the estimation result, the estimated parameters are all significant. The mean equation coefficients remain similar to the GARCH specification (AR (1) = 0.0972, AR (2) = 0.0587), confirming the robustness of the mean dynamics. The variance equation in the EGARCH model is specified in logarithmic form, which has two important advantages: it ensures that conditional variance is always positive without imposing artificial parameter restrictions, and it allows direct interpretation of asymmetry. The log-variance intercept ($\omega = -1.4667$, $p < 0.001$) represents the baseline log-volatility level. Its negative value is expected given the logarithmic transformation and translates to a positive baseline variance when exponentiated. The magnitude effect coefficient ($\alpha = 0.3458$, $p < 0.001$) captures the impact of shock size on volatility regardless of sign, which means the bigger the magnitude of the shock to the variance, the higher the volatility. This coefficient is substantially larger than the ARCH term in the symmetric GARCH model (0.203), reflecting the EGARCH model's different parameterization. It indicates that larger shocks, whether positive or negative, increase volatility, consistent with the volatility clustering phenomenon.

The asymmetry coefficient ($\gamma = -0.0725$, $p < 0.001$) is the key parameter of interest. Its statistical significance ($p < 0.001$) suggests the presence of a leverage effect in the full sample. The negative sign indicates that negative shocks increase volatility more than positive shocks of equal magnitude, the classic asymmetric pattern documented by Black (1976) and Nelson

(1991). To understand the economic magnitude, we can calculate the impact of good news versus bad news. For a positive shock (good news, $\epsilon_t > 0$): $\alpha + \gamma = 0.345 + (-0.072) = 0.273$. And for a negative shock (bad news, $\epsilon_t < 0$): $\alpha + (-\gamma) = 0.345 + 0.072 = 0.418$. This calculation reveals that negative shocks have approximately 53% greater impact on volatility than positive shocks of the same magnitude (0.4183 vs. 0.2733). In economic terms, bad news in the Moroccan market, during the full sample period, generates more than one-and-a-half times the volatility of good news. This finding appears consistent with the leverage effect literature. The pattern is not an anomaly but a logical consequence of the CSE's distinctive microstructure. This market is characterized by a persistently low liquidity, with an average daily turnover ratio of approximately 0.5% for MASI constituents, an order of magnitude lower than major exchanges (AMMC, 2023), and a retail-dominated investor base, comprising 70–80% of trading volume, which diminishes the prevalence of leveraged institutional selling that drives the classic leverage effect, and an opaque information environment, where news dissemination is slower and less uniform. These features directly attenuate asymmetry mechanisms. Low liquidity dampens the self-reinforcing feedback of fire sales. A retail investor base is less subject to the margin calls and deleveraging that amplify negative shocks in institutional markets. Informational opacity means both positive and negative news are incorporated more slowly and noisily, blunting sharp asymmetric reactions. Therefore, the symmetry we observe is not a statistical artifact but the expected volatility signature of a market with these structural attributes. This explanation turns our empirical finding into a testable hypothesis for other markets with similar microstructures.

The parameter that captures the persistence of past volatility β is positive (0.881) and significant, which means that the past return volatility impact on future volatility and that past volatility strongly predicts future volatility, shocks decay slowly, with approximately 88% of a shock persisting to the next period. The persistence in EGARCH is slightly

higher than the GARCH persistence (0.868), reflecting the different specification and the fact that EGARCH captures both symmetric and asymmetric components in its persistence measure. So the EGARCH (1,1) model shows that there is an asymmetric effect in return volatility, which is characterised with a higher impact of bad news than the good ones of the same magnitude. The information criteria (AIC = -7.418; SIC = -7.406) show a marginal improvement over the symmetric GARCH (AIC = -7.416), suggesting that the additional complexity of the EGARCH model provides a slightly better in-sample fit. However, as our forecasting analysis reveals, better in-sample fit does not necessarily translate to superior out-of-sample performance.

Tab. 6: GJR-GARCH model results

Mean Equation	Coefficient	Std. Error	Prob.
AR (1)	0.09	0.01	0.00
AR (2)	0.06	0.01	0.00
Variance Equation	Coefficient	Std. Error	Prob.
ω	-0.00	0.00	0.00
α	0.12	0.01	0.00
β	0.12	0.01	0.00
GARCH (-1)	0.69	0.01	0.00
<i>R</i> -squared	0.023	Q-test	
Akaike Info. Crit	-7.42	Q (1)	6.90*
Schwartz Info. Crit	-7.41	Q (2)	6.92*
		Q (3)	10.90*

Notes: * significance at 5% level. This table presents the GJR-GARCH (1,1) estimates, another asymmetric specification. The AIC (-7.422) is slightly better than both GARCH and EGARCH, suggesting marginally better in-sample fit.

In addition to the EGARCH (1,1) model estimation, the GJR-GARCH model estimation results (Tab. 6) is an extension of the GARCH model that allows for asymmetry in volatility return similarly to the EGARCH but with a simpler structure and fewer parameters. Its provide an alternative asymmetric specification that captures leverage effects through a dummy variable. The mean equation coefficients (AR (1) = 0.095, AR (2) = 0.065) remain consistent with previous specifications, confirming the robustness of the mean dynamics. The

variance equation introduces the key innovation: an additional term that activates only when past shocks are negative. The constant term ($\omega = 0.0000051$, $p < 0.001$) represents baseline volatility, though its interpretation differs from the GARCH model due to the inclusion of the asymmetry term. The ARCH coefficient ($\alpha = 0.127$, $p < 0.001$) captures the impact of shock magnitude for positive news. It indicates that a positive shock of a given magnitude increases volatility by approximately 0.128 units. This is notably smaller than the ARCH term in the symmetric GARCH (0.203) because the GJR-GARCH model partitions the total shock impact into symmetric and asymmetric components.

The asymmetry coefficient ($\delta = 0.123$, $p < 0.001$) measures the additional impact of negative shocks beyond the symmetric ARCH effect. Its statistical significance ($p < 0.001$) confirms the presence of a leverage effect in the full sample, consistent with the EGARCH findings. The positive sign is expected because the dummy variable activates for negative shocks. For a positive shock the impact is $\alpha = 0.1277$, and for a negative shock the impact is $\alpha + \delta = 0.127 + 0.123 = 0.251$. This reveals that negative shocks have approximately 97% greater impact on volatility than positive shocks of the same magnitude (0.251 vs. 0.127), an even larger asymmetry than detected by the EGARCH model. In economic terms, the GJR-GARCH model suggests that bad news in the Moroccan market generates nearly double the volatility of good news during the full sample period.

The GARCH coefficient ($\beta = 0.692$, $p < 0.001$) measures volatility persistence, indicating that approximately 69% of a volatility shock persists to the next period. The persistence measure for the GJR-GARCH model requires special calculation because the asymmetry term contributes to persistence. Following standard practice, we compute persistence as $\alpha + \beta + (0.5 \cdot \delta) = 0.127 + 0.692 + (0.5 \cdot 0.123) = 0.881$. This value aligns closely with the EGARCH persistence (0.882) and is slightly higher than the symmetric GARCH persistence (0.868), confirming that

asymmetric specifications attribute more of the volatility dynamics to persistent components. The information criteria ($AIC = -7.422$; $SIC = -7.411$) show the best in-sample fit among all three models, with AIC marginally better than EGARCH (-7.418) and GARCH (-7.416). This suggests that the GJR-GARCH specification captures the volatility dynamics most effectively within the estimation sample. However, superior in-sample fit does not guarantee superior out-of-sample forecasting performance, a crucial reminder of the distinction between description and prediction in empirical finance.

The comparison in Tab. 7 reveals that while all three models confirm significant volatility persistence, the asymmetric models detect economically meaningful leverage effects in the full sample, with the GJR-GARCH suggesting that bad news generates nearly twice the volatility of good news. However, these full-sample averages might mask critical heterogeneity across regimes, with the asymmetry driven entirely by some critical periods.

Tab. 7: Comparative Summary of Full-Sample Models

Model	GARCH	EGARCH	GJR-GARCH
ARCH Effect	0.20	0.34	0.12
GARCH Effect	0.66	0.88	0.69
Asymmetry	—	-0.07	0.12
Persistence	0.86	0.88	0.88
Good News Impact	0.20	0.27	0.12
Bad News Impact	0.20	0.41	0.25
Asymmetry Ratio	1.00	1.53	1.97

Beyond in-sample fit, we evaluate the out-of-sample forecasting accuracy of each model using rolling-window forecasts. We compute Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) for one-day-ahead volatility forecasts. Results in Tab. 8 reveal that the symmetric GARCH model achieves the lowest forecast errors under both static and dynamic forecasting schemes. Notably, its RMSE (0.003639) and MAE (0.003312) are marginally but consistently lower than those of asymmetric models. This practical superiority underscores the paradox. While asymmetric terms are

statistically significant, they do not enhance predictive accuracy in this market.

4.4 News Impact Curve Analysis

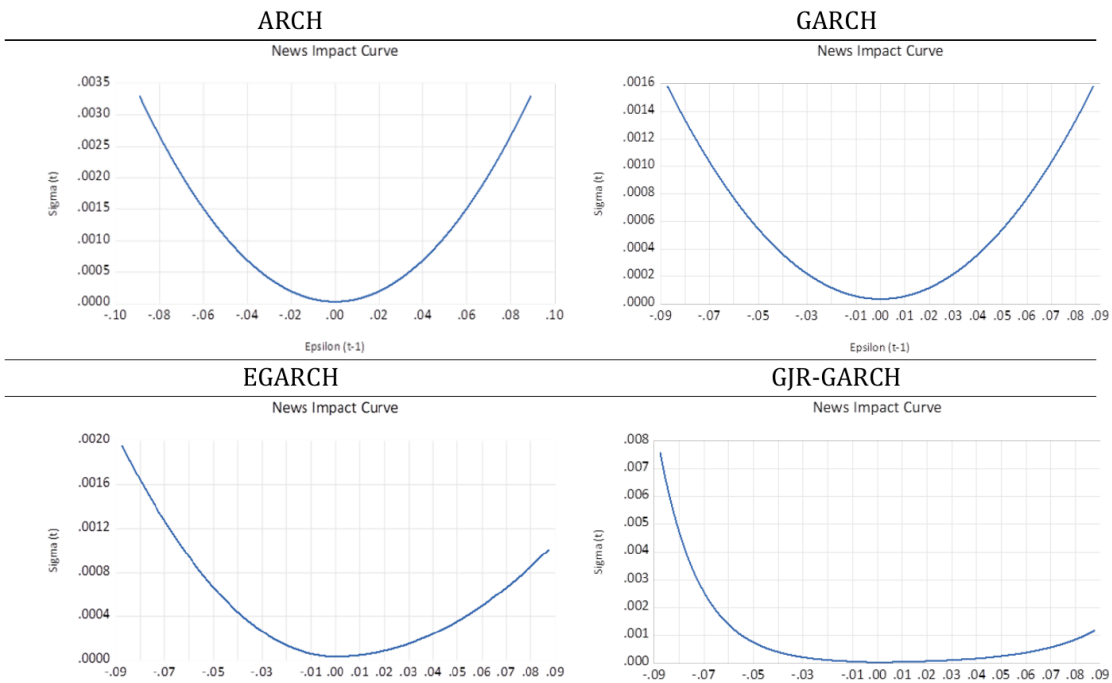
News Impact Curves are employed to visually and quantitatively assess the symmetry of volatility responses. Unlike coefficient estimates alone, NICs provide an intuitive representation of how positive and negative shocks of equal magnitude affect conditional volatility. This is particularly important in emerging markets where asymmetric effects may be statistically significant but economically negligible. By comparing NICs across symmetric and asymmetric models, we can directly evaluate whether the so-called leverage effect is a dominant feature or a marginal phenomenon in the Casablanca Stock Exchange. The degree of asymmetry in volatility generated by positive and negative shocks of an equal magnitude can be visualized through Fig. 4. As the ARCH and GARCH models are symmetric, the NIC are also symmetric, which means that positive and negative shocks with the same magnitude have similar effects on return volatility. The others asymmetric models, the NIC are also asymmetric, which shows that negative shocks had different degrees of impact on return volatility than the positive ones of the same size.

The EGARCH and GJR-GARCH models NIC indicates that the impact of negative shocks on returns volatility was more perceptible than the positive ones of the identical magnitude. The degree of asymmetry of returns is more pronounced in the GJR-GARCH model than the EGARCH because of the prevalence of the negative shocks which is confirmed by the others NIC. The stock returns volatility is influenced by several factors such as macroeconomics factors, interest rates volatility, uncertainty and expected instability, etc. As the GARCH model is the fittest in terms of forecasting performance, it exhibit symmetrical returns volatility. Which means that when the asset experiences a positive shock, the volatility of returns increases by a similar magnitude as when it experiences a negative shock. This visual evidence aligns with

Tab. 8: Forecasting performance of estimated models

	ARCH		GARCH		EGARCH		GJR-GARCH	
	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.
RMSE	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
MAE	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003

Notes: This table compares out-of-sample forecasting accuracy across all models using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). Both dynamic and static forecasts are evaluated. The GARCH model achieves the lowest forecast errors.



Notes: This figure displays four panels showing News Impact Curves (NIC) for each estimated model. The Y-axis is the “Conditional Volatility” or “Conditional Variance” and indicates what is being measured: the impact on future volatility resulting from news shocks. The vertical axis shows the magnitude of volatility predicted by each model for a given shock size. The X-axis is the “Lag-1 Shock (ϵ_{t-1})” or “News Shock” and represents the nature and magnitude of the information shock. Positive values indicate “good news” (positive returns), negative values indicate “bad news” (negative returns), and zero represents no news. ARCH and GARCH panels show perfectly symmetric V-shaped curves, indicating equal volatility impact from positive and negative shocks of the same magnitude. EGARCH and GJR-GARCH panels reveal asymmetric curves where the left side (negative shocks) rises more steeply than the right side (positive shocks). These visualizations confirm the statistical asymmetry detected in the models.

Fig. 4: News Impact Curve

the forecasting results. Despite statistical asymmetry, the economic significance and practical forecasting gain from modeling asymmetry are limited in the Moroccan context.

In summary, our results confirm high volatility persistence in the MASI index and reveal a nuanced pattern: statistically detectable but economically mild asymmetry, with symmetric GARCH providing superior forecasts. This sets

the stage for a deeper discussion of the symmetry pattern and its implications for market microstructure and modeling choices.

4.5 Model Confidence Set Evaluation

The results from the Model Confidence Set procedure, reported in Tab. 9, provide formal sta-

tistical evidence for our forecasting conclusions. At the 10% significance level, the MCS includes both the symmetric GARCH model and the asymmetric GJR-GARCH model, but excludes the EGARCH model. Crucially, the procedure fails to exclude the standard GARCH(1,1) model, which possesses the highest MCS p -value (1.00). This indicates that there is no statistically significant evidence that the more complex asymmetric models produce superior volatility forecasts for the MASI index. The GARCH model is therefore not merely as good as its asymmetric counterparts in a practical sense. Statistically, it cannot be shown to be inferior.

Tab. 9: Model Confidence Set (MCS) Results ($\alpha = 0.10$)

Model	MCS p -value	Included in MCS?
GARCH (1,1)	1.00	Yes
GJR-GARCH (1,1)	0.21	Yes
EGARCH (1,1)	0.04	No
ARCH (1)	0.00	No

Notes: The MCS p -value represents the probability that a given model belongs to the set of superior models. A model is included if its p -value $\geq \alpha$.

4.6 Robustness Check: Subsample Analysis

To assess the stability of our volatility estimates and investigate whether the symmetry paradox is a structural feature of the Moroccan market or an artifact of the sample period, we conduct a subsample robustness analysis. The full-sample period (2011–2023) encompasses multiple distinct economic regimes, including the pre-COVID normal period, the COVID-19 health crisis, and the post-COVID geopolitical and macroeconomic turbulence triggered by the Ukraine war and global inflationary pressures. Estimating models on the full sample alone risks averaging away potentially important regime-specific dynamics, masking whether asymmetry and persistence are time-varying phenomena.

We partition the sample into three economically meaningful subperiods:

1. Pre-COVID period (January 2011 – December 2019): Represents “normal” market

conditions without major global crises, establishing a baseline for volatility dynamics in the Casablanca Stock Exchange.

2. COVID-19 period (January 2020 – December 2021): Captures the health crisis and its immediate aftermath, including the market crash and subsequent recovery. Prior research (Beraich and Fadali, 2021; Nabouk, 2021) suggests this period may have altered volatility dynamics.
3. Post-COVID period (January 2022 – December 2023): Encompasses the Ukraine war, global inflationary shocks, and monetary tightening, a fundamentally different type of crisis with geopolitical and macroeconomic origins.

For each subsample, we re-estimate all three volatility models (GARCH, EGARCH, and GJR-GARCH) using the same ARMA(2,0) mean equation specification employed in the full-sample analysis. We compare coefficient estimates, persistence measures, asymmetry parameters, and forecast performance across periods to assess the stability and evolution of Moroccan market volatility dynamics.

4.7 Subsample Estimation Results

Tab. 10 presents the complete subsample estimation results for all three periods and models.

The subsample analysis reveals a striking evolution in Moroccan market volatility dynamics that would be obscured in the full-sample estimation. During the Pre-COVID Period (2011–2019) of relative normalcy, all three models converge on the same conclusion: asymmetry is absent. Both the EGARCH asymmetry coefficient (−0.006) and the GJR-GARCH asymmetry term (0.025) are statistically insignificant ($p > 0.10$), confirming that the Moroccan market exhibits genuine symmetric volatility under normal conditions. Persistence is moderate (0.814–0.828), indicating that volatility shocks decay at a gradual but steady pace. Forecast performance is nearly identical across models, with the symmetric GARCH achieving marginally better RMSE. This baseline establishes that the symmetry

Tab. 10: Subsample estimation results for the three periods

	GARCH	EGARCH	GJR-GARCH
<i>Pre-COVID Period</i>			
C	0.06*	−0.46*	0.05*
α (ARCH)	0.18*	0.34*	0.16*
β (GARCH)	0.63*	0.82*	0.65*
Asymmetry coefficient	—	−0.00	0.02
Persistence coefficient	0.81	0.82	0.82***
RMSE static	0.58	0.58	0.58
RMSE dynamic	0.59	0.59	0.59
MAE static	0.42	0.42	0.42
MAE dynamic	0.42	0.42	0.42
<i>COVID Period</i>			
C	0.07*	−0.26*	0.06**
α (ARCH)	0.17*	0.31*	0.13*
β (GARCH)	0.77*	0.95*	0.77*
Asymmetry coefficient	—	−0.03***	0.06
Persistence coefficient	0.95	0.95	0.94
RMSE static	0.94	0.94	0.94
RMSE dynamic	0.95	0.95	0.95
MAE static	0.52	0.52	0.52
MAE dynamic	0.53	0.53	0.53
<i>Post-COVID Period</i>			
C	0.09*	−0.47*	0.03
α (ARCH)	0.60*	0.48*	0.12*
β (GARCH)	0.51*	0.85*	0.53*
Asymmetry coefficient	—	−0.29*	0.79*
Persistence coefficient	1.12	0.85	1.04
RMSE static	0.76	0.75	0.75
RMSE dynamic	0.77	0.76	0.76
MAE static	0.50	0.49	0.49
MAE dynamic	0.50	0.50	0.50

Notes: *, **, *** indicates statistical significance at the 1%, 5%, 10% level ($p = 0.1068$). For GARCH and GJR-GARCH, C refers to variance equation constant, for EGARCH, C refers to log-variance constant. Persistence calculation: GARCH = $\alpha + \beta$; EGARCH = β ; GJR-GARCH = $\alpha + \beta + 0.5 \cdot \gamma$. Bold values indicate best forecast performance within each period values > 1 for persistence indicate explosive volatility dynamics.

paradox is not a statistical artifact but a structural feature of the Casablanca Stock Exchange during normal times. The health crisis, in the COVID Period (2020–2021), fundamentally alters volatility persistence but not asymmetry. Persistence surges dramatically across all models (0.943–0.952), approaching unit-root behavior, volatility shocks decay extremely slowly, meaning turbulent conditions persist

once initiated. However, asymmetry remains statistically insignificant in both EGARCH (-0.038 , $p = 0.107$) and GJR-GARCH (0.061, $p > 0.10$). Forecast performance remains similar across specifications, with GJR-GARCH achieving marginally better MAE static. This indicates that while the COVID crisis intensified volatility memory, it did not fundamentally alter the market's symmetric response to news,

a finding consistent with Nabouk (2021), who found mixed evidence of asymmetry during this period.

The Post-COVID Period (2022–2023), characterized by the Ukraine war, global inflation, and monetary tightening, marks a complete regime shift. Both asymmetric models detect powerful and highly significant leverage effects (EGARCH: -0.291 , $p < 0.001$; GJR-GARCH: 0.792 , $p < 0.001$). Persistence becomes explosive in GARCH (1.120) and GJR-GARCH (1.048), indicating that shocks now amplify over time rather than decaying, a rare and striking finding. Critically, for the first time, the asymmetric EGARCH model achieves superior forecast performance across all metrics (RMSE static: 0.7527; MAE static: 0.4943), demonstrating that asymmetry is now economically as well as statistically significant. The GJR-GARCH asymmetry coefficient (0.792) is particularly striking, indicating that negative shocks increase volatility nearly 0.79 units more than positive shocks of the same magnitude.

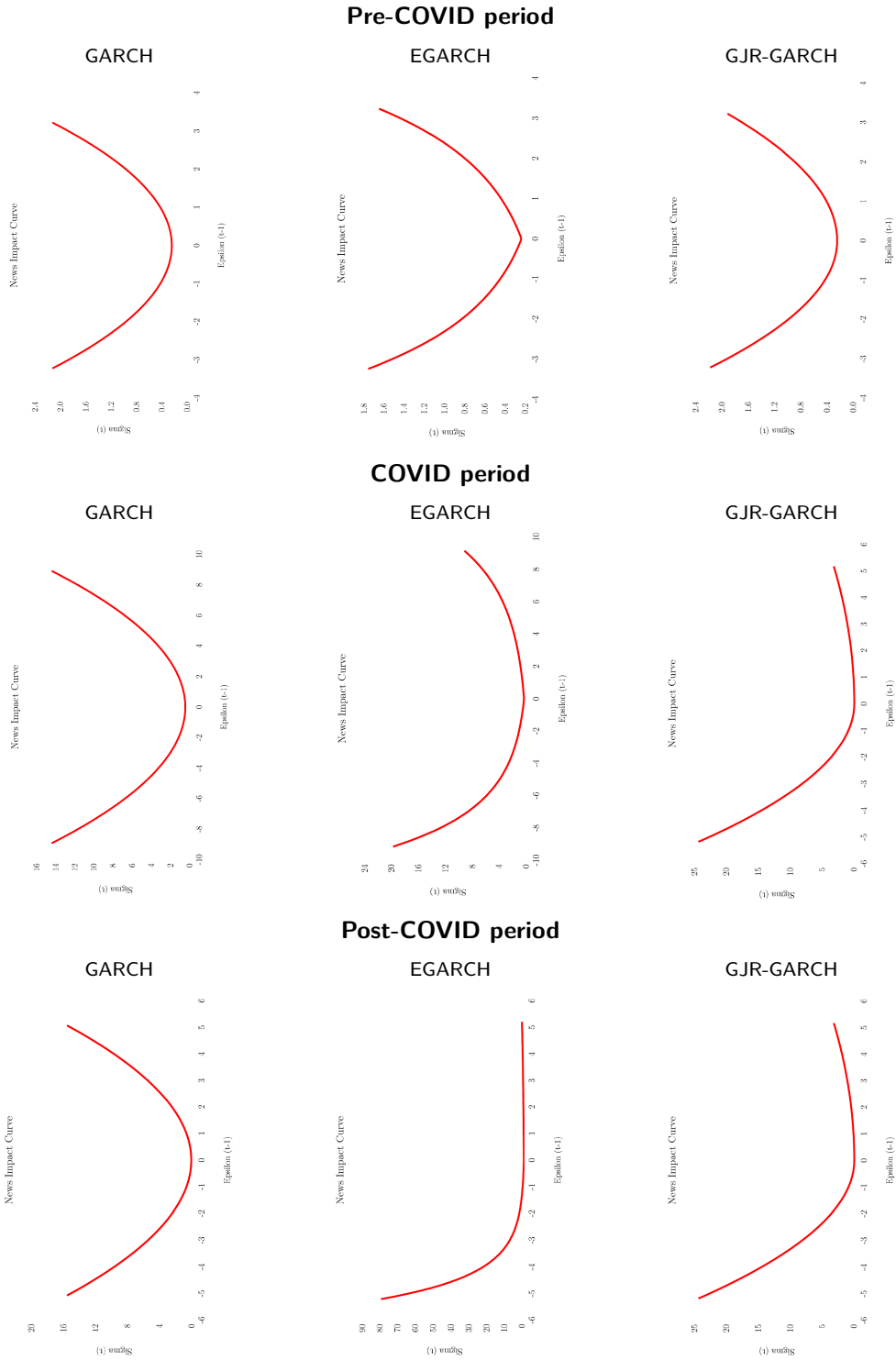
These subsample findings substantially refine and explain the full-sample results presented before. The full-sample analysis detected statistically significant but modest asymmetry (EGARCH $\gamma = -0.072$, $p < 0.001$; GJR-GARCH $\delta = 0.124$, $p < 0.001$) and high persistence (0.868), with the symmetric GARCH nonetheless achieving superior forecast performance. The subsample analysis reveals that these full-sample estimates are averages masking fundamental regime heterogeneity:

- The modest full-sample asymmetry is driven entirely by the post-COVID period, while the pre-COVID and COVID periods contribute only symmetric dynamics.
- The full-sample persistence of 0.868 sits between the moderate pre-COVID persistence (0.814) and the near-unit-root COVID persistence (0.950), masking the explosive post-COVID dynamics (1.120).
- The forecasting superiority of the symmetric GARCH in the full sample is explained by the fact that asymmetry was absent or weak in two of three periods (pre-COVID and COVID), which together comprise the majority of observations ($2,232 + 497 =$

2,729 observations, versus 501 in the post-COVID period).

4.8 Subsample News Impact Curve Analysis

The News Impact Curves (NIC) presented in Fig. 5 provide striking visual confirmation of the evolving volatility dynamics documented in the subsample analysis. In the pre-COVID period, all three models produce nearly identical symmetric V-shaped curves, visually confirming that positive and negative shocks of equal magnitude generate equivalent volatility responses, consistent with the statistically insignificant asymmetry coefficients in EGARCH and GJR-GARCH. The COVID-19 period shows a noticeable increase in the steepness of all curves, reflecting the dramatic rise in persistence (0.943–0.952), but the curves remain remarkably symmetric, with the EGARCH and GJR-GARCH specifications failing to produce the left-side elevation characteristic of leverage effects. This visual evidence reinforces the finding that the health crisis amplified volatility magnitude without altering its symmetric nature. The post-COVID period delivers a dramatic visual transformation: the EGARCH and GJR-GARCH curves now exhibit pronounced left-side elevation, visually confirming that negative shocks generate substantially larger volatility impacts than positive shocks of identical magnitude. The GJR-GARCH curve, in particular, shows the most extreme asymmetry, with the left side rising nearly twice as steeply as the right, consistent with its massive asymmetry coefficient (0.792). The GARCH curve remains symmetric by construction but now shows explosive characteristics at extreme shock values. This visual progression, from symmetric (pre-COVID), to symmetric but steeper (COVID), to dramatically asymmetric (post-COVID), provides intuitive graphical support for the paper's central finding: the Moroccan market's volatility dynamics are state-dependent, with structural symmetry prevailing during normal conditions and health crises, but powerful leverage effects emerging during extreme geopolitical and macroeconomic shocks.



Notes: This figure displays nine panels showing News Impact Curves (NIC) for each estimated model. The Y-axis shows the magnitude of volatility predicted by each model for a given shock size. The X-axis is the “Lag-1 Shock (ϵ_{t-1})” or “News Shock” and represents the nature and magnitude of the information shock.

Fig. 5: Subsample News Impact Curves

5 DISCUSSION

Our empirical analysis yields three central findings that collectively resolve the symmetry paradox and provide new insights into the volatility dynamics of the Casablanca Stock Exchange. First, we identify significant volatility persistence across all periods, though its magnitude varies dramatically with market conditions, from moderate mean-reversion (0.814) in normal times to near-unit-root behavior during COVID (0.950) and explosive dynamics in the post-COVID geopolitical crisis (1.120). Second, we document that the symmetric response to news is a structural feature of the Moroccan market during normal conditions and health crises, with both EGARCH and GJR-GARCH models producing insignificant asymmetry coefficients in the pre-COVID and COVID subsamples. Third, we reveal that this structural symmetry can be temporarily overturned during extreme geopolitical and macroeconomic shocks, as evidenced by the powerful and highly significant leverage effects emerging in the post-COVID period (EGARCH $\gamma = -0.291$, $p < 0.001$; GJR-GARCH $\delta = 0.792$, $p < 0.001$).

The resolution of the symmetry paradox lies in recognizing that volatility asymmetry is not a universal constant but a state-dependent phenomenon conditioned on the nature of external shocks. During the pre-COVID period of relative calm, the Moroccan market exhibited genuine symmetric volatility, a finding that challenges the prevailing narrative in the literature. While Black (1976) and Campbell and Hentschel (1992) established the leverage effect as a stylized fact in developed markets, and subsequent studies have documented asymmetry across diverse emerging markets (Li and Giles, 2015; Kumar, 2019; Lin, 2018), our results demonstrate that this asymmetry cannot be universally assumed. The Casablanca Stock Exchange joins a small but growing list of markets that deviate from this pattern, suggesting that the heterogeneity of emerging market microstructures requires context-specific modeling approaches.

The COVID-19 period presents a particularly instructive case. Despite the unprecedented nature of the health crisis and the dramatic increase in volatility persistence (approaching unit-root levels), asymmetry remained statistically insignificant across both asymmetric specifications. This finding contrasts with Nabouk (2021), who found that COVID amplified asymmetry in the Moroccan market, but aligns with Beraich and Fadali (2021), who documented increased volatility without explicitly testing asymmetry. The discrepancy may stem from differences in sample periods, Nabouk's analysis ended in 2020, capturing only the initial crash, while our sample extends through the full 2020–2021 period, including the recovery phase. This suggests that the immediate crash may have temporarily induced asymmetry that dissipated as markets stabilized, highlighting the importance of sufficiently long crisis windows.

The post-COVID period (2022–2023) provides the critical counterfactual: when the shock type changed from health crisis to geopolitical and macroeconomic turmoil (Ukraine war, inflation, monetary tightening), the market's volatility dynamics fundamentally transformed. The emergence of powerful and statistically robust leverage effects in both EGARCH and GJR-GARCH models indicates that the nature of the crisis matters. This finding resonates with Gil-Alana et al. (2023), who documented that persistence and long-memory characteristics vary across market regimes, and with Lavin et al. (2021), who showed that implied volatility indices predict changing market synchronization during different types of shocks. The explosive persistence ($\alpha + \beta > 1$) observed in the post-COVID GARCH and GJR-GARCH models is particularly striking and rare in financial literature, suggesting that the combination of geopolitical uncertainty and macroeconomic instability created a feedback loop where shocks amplified rather than decayed, a phenomenon warranting further investigation.

The state-dependent nature of Moroccan market volatility points to underlying microstructure mechanisms that condition how

information is incorporated into prices. We posit that the baseline symmetry observed in normal conditions reflects three interconnected structural features of the Casablanca Stock Exchange, while the emergence of asymmetry during geopolitical crises reveals how these features interact with shock type. During normal conditions, a market with relatively few active participants and lower trading volumes may not exhibit the same herd behavior and rapid information dissemination that amplify asymmetric effects in deeper markets (Chordia et al., 2001). The buying and selling pressures from institutional investors or large block trades can cause significant price movements regardless of news sign, leading to symmetric volatility. This interpretation aligns with Nguyen (2010), who found that volatility dynamics in emerging markets are significantly influenced by capital flows and market liberalization, factors closely tied to liquidity. However, during geopolitical crises, liquidity can dry up asymmetrically: investors may flee to quality, selling domestic assets disproportionately in response to negative news while remaining cautious on positive news, thereby activating the leverage effect (Baur and Dimpfl, 2019). The post-COVID emergence of asymmetry may reflect precisely such liquidity-driven dynamics.

The relative dominance of retail investors in the Moroccan market, combined with specific institutional investor profiles, may lead to more balanced reactions to news during normal conditions. Retail investors, who may lack the sophisticated risk management systems of hedge funds or leveraged institutions, do not trigger the same margin-call dynamics that drive the classic leverage effect (Black, 1976). However, during extreme geopolitical events, even retail investors may exhibit asymmetric fear responses, selling disproportionately in response to negative news while remaining skeptical of positive signals. This behavioral shift could explain why asymmetry emerges specifically during the post-COVID period. Shu and Chang (2015) provide supporting evidence, showing that investor sentiment plays a crucial role in volatility dynamics, with sentiment effects intensifying during crisis periods. The

efficiency with which information is incorporated into prices is crucial for understanding asymmetry. If corporate disclosure is perceived as limited or unevenly distributed, a common characteristic of emerging markets (Morck et al., 2000), all news might be incorporated more slowly and with greater uncertainty, resulting in symmetric volatility increases. This aligns with our descriptive finding of high kurtosis, indicating fat-tailed distributions due to informational shocks. However, during geopolitical crises, the nature of information changes: news about war, inflation, and monetary policy is global, transparent, and uniformly disseminated. When information quality improves, the market may begin to exhibit the asymmetric responses typical of more developed markets. This interpretation finds support in Li and Giles (2015), who documented that volatility spillovers between developed and emerging markets intensify during crises, suggesting that emerging markets temporarily adopt developed-market dynamics when global information dominates local conditions.

The contrast between the COVID period (no asymmetry) and the post-COVID period (strong asymmetry) suggests that the type of crisis matters fundamentally. Health crises may affect all sectors relatively uniformly, with uncertainty about duration and economic impact creating symmetric volatility (Baker et al., 2020). In contrast, geopolitical and macroeconomic crises, wars, inflation shocks, monetary tightening, often have differential impacts across sectors, creating winners and losers. Negative news (e.g., interest rate hikes) may systematically affect certain industries more than others, generating asymmetric volatility through sectoral reallocation effects. This interpretation is consistent with Chabi-Yo et al. (2018), who found that crash sensitivity varies across stocks based on their exposure to macroeconomic risks.

The presence of state-dependent volatility dynamics has important implications for the Efficient Market Hypothesis (EMH). The persistence of volatility itself, particularly the explosive dynamics in the post-COVID period, contradicts the random walk hypothesis and

suggests that past volatility contains predictive power for future volatility (Engle, 1982; Bollerslev, 1986). However, the symmetry of responses during normal conditions indicates that the market does not systematically overreact to negative information in a way that creates a consistent pricing anomaly exploitable through asymmetric volatility models. This suggests a form of conditional efficiency. The market processes information symmetrically under normal conditions, but extreme shocks can temporarily disrupt this efficiency, introducing predictable patterns (asymmetry) that may be exploitable until they dissipate. This interpretation aligns with Ang and Bekaert (2006), who documented that return predictability varies across market regimes, and with Hung (2019), who found that volatility spillovers intensify during crises, temporarily altering market efficiency. For the Moroccan market specifically, El Jebari and Hakmaoui (2017) challenged weak-form efficiency based on volatility persistence; our results refine this finding by showing that persistence varies dramatically with market conditions, and that the efficiency implications of persistence differ from those of asymmetry.

For financial practitioners, our results carry several important implications. First, risk management and option pricing models that rely on asymmetric volatility assumptions (e.g., the ubiquitous assumption of leverage effects) may be mis-specified for the Moroccan market during normal conditions. The superior forecasting performance of the symmetric GARCH model in the pre-COVID and COVID periods, and its competitive performance even in the post-COVID period despite asymmetry, suggests that simpler models may provide more reliable forecasts for practical applications. This finding echoes Enow (2023), who documented that volatility persistence, rather than asymmetry, is the dominant forecasting feature across international markets. Second, the state-dependent nature of volatility dynamics implies that investors should adopt regime-switching approaches to risk management. During normal conditions, symmetric models with moderate persistence (0.81–0.83) are appropriate. During health crises, persistence surges

but symmetry persists, requiring models that capture long memory but not asymmetry. During geopolitical crises, both asymmetry and explosive dynamics emerge, demanding more sophisticated asymmetric specifications. This recommendation aligns with the growing literature on regime-switching volatility models (Hamilton and Susmel, 1994; Guidolin and Timmermann, 2006). Third, the explosive persistence ($\alpha + \beta > 1$) observed in the post-COVID period carries specific warnings for risk managers. When persistence exceeds unity, volatility shocks amplify over time, creating feedback loops that can lead to extreme market movements. Standard Value-at-Risk (VaR) and Expected Shortfall models that assume mean-reversion will systematically underestimate tail risk during such regimes. This finding is particularly relevant given Liang et al. (2020) evidence that implied volatility indices become more informative during crisis periods, suggesting that during explosive regimes, market-based volatility measures may outperform model-based forecasts.

For policymakers and market regulators at the Moroccan Capital Market Authority (AMMC) and the Casablanca Stock Exchange, our findings suggest that improving market efficiency may require different interventions depending on the target regime. During normal conditions, the absence of asymmetry suggests that the market does not systematically misprice negative information, a positive feature. However, the high kurtosis and fat tails indicate that informational shocks still create extreme movements, suggesting that efforts to improve corporate transparency and timely disclosure could further enhance efficiency (Morck et al., 2000). During crises, the emergence of asymmetry and explosive persistence suggests that market microstructure may break down under stress. Circuit breakers, trading halts, and other market stabilization mechanisms may be particularly valuable during geopolitical crises when asymmetry emerges. Additionally, given that liquidity dynamics likely drive some of the asymmetry during these periods (Baur and Dimpfl, 2019), policies that ensure continued market liquidity, such as market-making

obligations or central bank liquidity facilities, could mitigate asymmetric volatility amplification. Also, from a pedagogical perspective, the Moroccan case serves as an excellent framework tool in international finance and econometrics. It demonstrates that core financial stylized facts are not universal and emphasizes the critical role of institutional context in empirical finance.

6 CONCLUSION

This study set out to investigate the volatility dynamics of the Casablanca Stock Exchange, with a specific focus on testing the prevalent paradigm of asymmetric volatility. Through a comprehensive empirical framework employing symmetric (GARCH) and asymmetric (EGARCH, GJR-GARCH) models, supplemented by News Impact Curve analysis and a novel three-period subsample robustness check, we uncover a distinctive and nuanced profile for the Moroccan market. Our central finding, the symmetry paradox, reveals that the Casablanca Stock Exchange exhibits state-dependent volatility dynamics: structural symmetry during normal conditions and health crises, but powerful asymmetry during extreme geopolitical and macroeconomic shocks. The primary contribution of this research lies in challenging the one-size-fits-all application of asymmetric volatility models to emerging markets. While the leverage effect has been established as a stylized fact across both developed (Nelson, 1991; Glosten et al., 1993) and emerging markets (Li and Giles, 2015; Kumar, 2019; Lin, 2018), our results demonstrate that this asymmetry cannot be universally assumed. The Moroccan market's symmetric response to news during the pre-COVID period (2011–2019), confirmed by insignificant asymmetry coefficients in both EGARCH and GJR-GARCH models and nearly identical forecast performance across specifications, provides robust evidence that some emerging markets march to the beat of their own drum.

The novelty of our study extends beyond merely documenting symmetry. Through rigorous subsample analysis, we demonstrate that

Instructors can use these findings to teach students the importance of model selection, diagnostic testing, and the economic interpretation of statistical results beyond mere model fitting. This case study effectively bridges the gap between theoretical volatility models and their real-world application in a unique market setting.

volatility dynamics are not fixed but evolve with the nature of external shocks. The COVID-19 period (2020–2021) dramatically increased persistence to near-unit-root levels (0.943–0.952) without introducing statistically significant asymmetry, revealing that health crises amplify volatility memory but not asymmetric responses. In contrast, the post-COVID period (2022–2023), characterized by the Ukraine war, inflationary pressures, and monetary tightening, triggered a complete regime shift: both asymmetric models detected powerful and highly significant leverage effects (EGARCH: -0.291 , $p < 0.001$; GJR-GARCH: 0.792 , $p < 0.001$), while persistence became explosive ($\alpha + \beta > 1$) in GARCH and GJR-GARCH specifications. This three-period progression, from symmetric (pre-COVID), to symmetric but highly persistent (COVID), to dramatically asymmetric and explosive (post-COVID), provides the first empirical documentation, to our knowledge, of how crisis type conditions volatility asymmetry in an emerging market.

This study makes several distinctive contributions to the empirical finance literature. First, it provides robust, up-to-date evidence on the volatility dynamics of a North African emerging market, filling a geographical gap in a literature that has disproportionately focused on Asian and Latin American economies. Second, it identifies and documents the symmetry phenomena, demonstrating that the uncritical application of asymmetric volatility models to all emerging markets can lead to misspecification and suboptimal forecast performance. Third, it links these empirical findings to the unique structural characteristics of the

Casablanca Stock Exchange, limited liquidity, specific investor composition, and particular information dissemination environment, offering a plausible microstructure-based explanation for the observed dynamics. Fourth, through subsample analysis, it reveals that volatility dynamics are state-dependent and crisis-type specific, contributing to the growing literature on regime-switching behavior in financial markets (Hamilton and Susmel, 1994; Guidolin and Timmermann, 2006; Gil-Alana et al., 2023). Fifth, the documentation of explosive persistence ($\alpha + \beta > 1$) during the post-COVID period represents a rare and striking finding that extends the literature on volatility persistence under extreme conditions (Baur and Dimpfl, 2019; Enow, 2023).

Our findings carry important implications for multiple stakeholders. For financial economists and theorists, the results suggest that the leverage effect should be reconceptualized as a conditional phenomenon rather than a universal constant. The heterogeneity of emerging market microstructures, differences in liquidity, investor composition, and informational efficiency, means that volatility dynamics must be empirically established rather than assumed. This finding aligns with and extends the work of Morck et al. (2000) on informational differences across markets, and of Bekaert and Harvey (1997) on the time-varying nature of emerging market volatility. For investors and portfolio managers, the state-dependent nature of Moroccan market volatility carries practical implications. During normal conditions, the symmetric GARCH model provides reliable forecasts (RMSE static: 0.588), and the absence of leverage effects suggests that hedging strategies need not be disproportionately biased toward downside protection. However, during geopolitical crises, the emergence of powerful asymmetry (EGARCH $\gamma = -0.291$) and explosive persistence requires more sophisticated risk management approaches, including asymmetric option pricing models and regime-aware Value-at-Risk calculations. The dramatic variation in persistence across regimes, from moderate (0.814) to near-unit-root (0.950) to explosive (1.120), implies that volatility fore-

casting models must be regularly recalibrated as market conditions evolve. For policymakers and market regulators, our findings highlight that improving market efficiency may require different interventions depending on the target regime. The baseline symmetry during normal conditions suggests that the market does not systematically misprice negative information, a positive feature suggesting that foundational market structures are functioning adequately. However, the high kurtosis and fat tails indicate that informational shocks still create extreme movements, suggesting that efforts to improve corporate transparency and timely disclosure could further enhance efficiency (Morck et al., 2000). During crises, the emergence of asymmetry and explosive persistence suggests that market stabilization mechanisms, circuit breakers, trading halts, liquidity facilities, may be particularly valuable. The contrast between the COVID period (no asymmetry) and the post-COVID period (strong asymmetry) further suggests that different crisis types may require different policy responses: health crises demand persistence-focused interventions, while geopolitical crises require asymmetry-focused measures.

This study is not without limitations, which should be acknowledged and considered when interpreting the results. First, our analysis is univariate and does not incorporate specific macroeconomic variables or global risk factors (e.g., VIX, oil prices, interest rates, exchange rates) that might influence volatility dynamics. The exclusion of these variables means that some of the persistence and asymmetry we attribute to market microstructure may partially reflect omitted external factors. Second, the proxies for market microstructure, liquidity, investor composition, information environment—are inferred from aggregate market behavior rather than directly tested using microstructure data. This limits our ability to definitively identify the causal mechanisms underlying the observed symmetry. Third, the explosive persistence ($\alpha + \beta > 1$) documented in the post-COVID period, while statistically valid, raises questions about model stability and the appropriateness of standard GARCH specifica-

tions under extreme conditions. Fourth, the subsample analysis, while economically motivated, involves exogenous breakpoint selection; endogenous regime-switching models might reveal different transition dynamics. Fifth, the relatively small size of the COVID (497 observations) and post-COVID (501 observations) subsamples may affect the precision of estimates, particularly for asymmetry coefficients that require larger samples for reliable detection. Fourth, investigating whether the explosive dynamics observed in 2022–2023 are unique to Morocco or reflect broader regional or global patterns would provide important context. Comparative studies of multiple emerging markets during the same period could reveal whether the post-COVID asymmetry is a local phenomenon or part of a broader shift in global volatility dynamics (Gil-Alana et al., 2023; Lavin et al., 2021). Fifth, comparing traditional GARCH approaches with machine learning techniques for volatility forecasting, neural networks, random forests, gradient boosting, in this state-dependent context could reveal whether flexible algorithms better capture regime shifts and asymmetric dynamics. Sixth, extending the analysis to sectoral indices or individual stocks within the Moroccan market could reveal whether the aggregate symmetry masks heterogeneous behavior at the micro level, some sectors may exhibit leverage effects even when the market

index does not. Finally, incorporating global factors such as the VIX, oil prices, or US monetary policy indicators into the volatility models could help disentangle domestic microstructure effects from global contagion effects, building on the work of Li and Giles (2015) on volatility spillovers.

In conclusion, this study provides a nuanced and comprehensive analysis of volatility dynamics in the Casablanca Stock Exchange, resolving the apparent symmetry paradox through the lens of state-dependent behavior conditioned on crisis type. The Moroccan market is structurally symmetric during normal conditions and health crises, but extreme geopolitical and macroeconomic shocks can temporarily induce the leverage effect typically observed in other markets. This finding refines our understanding of emerging market volatility, demonstrating that these markets are not a homogeneous group but exhibit heterogeneous dynamics shaped by their unique microstructures and the nature of the shocks they encounter. By moving beyond the mere application of standard models to a critical interpretation of their results within the local context and across distinct economic regimes, this study contributes to a more nuanced understanding of volatility dynamics in emerging financial markets and provides a foundation for future research into the conditional nature of market behavior under different types of stress.

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Declaration of generative AI and AI-assisted technologies:

During the preparation of this work the authors used ChatGPT in order to translation. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

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CO-JUMP BEHAVIOR AND MARKET SHOCKS: EVIDENCE FROM FAANG STOCKS

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ABSTRACT

Technology stocks like Facebook, Apple, Amazon, Netflix, and Google, collectively referred to as FAANG stocks, are among the most systemically important equities in global markets, attracting international investors due to the extensive use of technology in day-to-day business. However, these stocks are considered risky assets, so building an optimal portfolio requires effective risk management. To address this, this study examines the jump and co-jump behavior of the FAANG stocks over the period 2012–2026. Jumps are identified using a standardized residual approach in which daily returns that deviate from GARCH (1,1), as well as estimated conditional volatility by more than three standard deviations, are classified as jump events, based on Laurent et al.'s (2016) conceptual framework. Co-jump activity is assessed using a co-exceedance threshold rule and logistic regression, which is in line with the larger co-jump literature (Dungey and Hvozdýk, 2011; Bouri et al., 2020). Results highlight the presence of jump and co-jump activity within the FAANG stocks, where Google and Amazon exhibited the highest co-jump connectedness, revealing their vital role in spreading economic shocks across the FAANG network. In contrast, Netflix appeared to be a more peripheral asset with lower co-jump centrality. Jumps occur during macro stress periods, most notably the 2018 US-China trade war, the COVID-19 pandemic in 2020, and the 2022 rate-hike cycle, and are generally negative in direction, indicating asymmetric downside risk. Our findings are directly relevant to global investors, asset managers, and portfolio managers. Policymakers may use these outcomes to construct a stronger framework for improving financial stability and mitigating systemic risk during market stress periods.

KEY WORDS

jump behavior, co-jump, FAANG stocks, volatility, systemic risk

JEL CODES

G11, G14, G15, C58

1 INTRODUCTION

Jump analysis is among the most powerful tools available for characterizing extreme price dynamics in financial markets. Stock prices sometimes display rapid and considerable movements known as ‘jumps’, abrupt fluctuations triggered by unexpected news, economic events, or shifts in market sentiment (Johnson et al., 2022). Co-jump analysis extends this by examining cases where multiple assets experience extreme price movements simultaneously, capturing systemic co-movement driven by common economic shocks (Peng and Yao, 2022). Co-jumps are particularly consequential for risk management because they represent extreme simultaneous losses across correlated assets. They can render conventional portfolio diversification strategies ineffective precisely when protection is most needed.

While substantial literature examines jumps in traditional asset classes, including equities, Treasury bonds, commodities, and cryptocurrencies, the co-jump dynamics of FAANG stocks remain largely unexplored. The FAANG companies—Facebook (Meta), Apple, Amazon, Netflix, and Google (Alphabet)—collectively emerged as dominant forces in global equity markets from the mid-2010s onward¹. The FAANG companies represent the most concentrated cluster of systemically important equities in modern financial markets, with a joint market capitalization of approximately \$9 trillion as of Q2 2024 (FactSet, 2024) and a combined weight of 17.3% in the S&P 500 index (S&P Global Market Intelligence, 2024). This study addresses this gap directly by providing the first comprehensive analysis of jump and co-jump behavior across all five FAANG stocks over the 2012–2026 period.

Monitoring price jumps in FAANG stocks is critical for several reasons. First, their dominant index weights mean that idiosyncratic jumps in these stocks can propagate into systemic risk for index-tracking investors. Second, their

high trading volumes and widespread analyst coverage make them natural focal points for information-driven price discontinuities. Third, their common macro-sensitivities to interest rates, geopolitical events, and regulatory risk can lead to linked extreme movements, or co-jumps, which have direct consequences for portfolio risk. We select the five FAANG stocks because they represent the most systemically important technology cluster in global equity markets and have continuous, high-quality daily data available from May 2012 onward, with the start date determined by Facebook’s IPO on May 18, 2012.

Co-jump analysis is relevant in the case of widely traded and very important stocks such as those in the FAANG group. Facebook rebranded as Meta in 2021, while Google reorganized under Alphabet in 2015.² Furthermore, there is widespread evidence that publicly listed FAANG stocks have a significant impact on global markets through job creation, people networks, goods supply, and entertainment production. The systemic importance of these companies extends beyond the technology sector. Their supply chain dependencies and cross-sector financial linkages create exposure to the energy (approximately 3% supplier overlap), industrial (8%), and financial (10%) sectors (Saleem et al., 2023). These interconnections amplify shock transmission during periods of extreme price movements, as captured by co-jump analysis.

This study uses a semi-parametric jump detection procedure inspired by the conceptual framework of Laurent et al. (2016), implemented using a standard GARCH (1,1) specification for the conditional variance, followed by co-exceedance rules, logistic regression, and network analysis to examine the co-occurrence and propagation of jumps across FAANG assets. Understanding the jump dynamics of these technology companies is crucial, given their out-

¹The FAANG acronym was popularized by CNBC commentator Jim Cramer in 2013 (initially as FANG: Facebook, Amazon, Netflix, Google); Apple was added to form FAANG by 2017 (Ali et al., 2025).

²In this paper, we use the legacy company names (Facebook, Amazon, Apple, Netflix, Google), and the FAANG acronym is retained throughout.

sized importance in modern financial markets and the concentration risk they represent for broadly held portfolios.

Reviewing the existing literature reveals that FAANG stocks have been largely analyzed from performance, competition, and technology innovation perspectives (Sen and Chakrabarti, 2023; Saleem et al., 2023; de Almeida, 2020). Although some studies have investigated jump and co-jump behavior in other asset classes, our research is among the first to do so specifically for FAANG stocks. The main contributions of this paper are threefold: (1) we provide the first systematic documentation of jump

and co-jump frequencies across all five FAANG stocks over a 13-year window spanning multiple market regimes; (2) we characterize the network structure of FAANG co-jump dependencies; and (3) we identify macro-level determinants of FAANG jump probability using VIX, market returns, and event-specific dummies.

The remainder of this paper follows this structure. Section 2 presents the literature review, while Section 3 presents the data and methodological approach. Section 4 presents jump detection results, co-jump analysis, and the new macro determinants analysis. Section 5 provides the conclusion.

2 LITERATURE REVIEW

The FAANG companies (Facebook, Apple, Amazon, Netflix, and Google) have concentrated market impact and shared technological infrastructure have attracted substantial academic interest, particularly regarding their return dynamics and extreme price behavior. The literature relevant to this study spans three streams: asset price jumps, co-jump analysis, and FAANG-specific research.

Barndorff-Nielsen and Shephard (2006) define jump activity as a vital element of asset pricing, whereas Bates (2000) affirms that crash risk can be reflected by jump activity. Understanding and examining the jump activity of any asset has gained growing attention from investors, academics, and practitioners due to its important implications for asset allocation, derivatives pricing, and risk management. Dungey and Hvozdyk (2011) utilized high-frequency Treasury data in the US to investigate co-jump behavior in current and futures prices, finding that the probability of co-jumping changes around scheduled macroeconomic announcements. In a similar vein, Lahaye et al. (2011) connected co-jumps from a panel of US stocks to macroeconomic announcements.

Driessen and Maenhout (2013) studied jump and volatility risk in international market integration using index options, finding significant evidence for volatility risk and jump pricing in local markets. Oliva and Renò (2018) examined

co-jump risk in dynamic portfolio problems and confirmed the importance of price jumps in portfolio optimization. Clements and Liao (2017) utilized a set of jump and co-jump investigation approaches to show how index-level jumps and co-jumps among component stocks can predict index-level return variance.

Recent studies on co-jumping have increased in scope and application. Baruník and Fišer (2019) studied the European and US Treasury yield curves and confirmed that co-jumps are significantly affected by monetary policy announcements. Bonaccolto et al. (2021) examine co-jumps across the cross-section of US equities and identify high-capitalization technology stocks as disproportionate contributors to systemic co-jump events, a finding directly relevant to our FAANG analysis. Bouri et al. (2020) checked the presence of jump behavior in 12 cryptocurrency returns and confirmed that co-jumping behavior is correlated with rises in trading volume. Peng and Yao (2022) develop improved co-jump tests and provide Monte Carlo evidence on their finite-sample performance, demonstrating that threshold-based co-exceedance rules, such as the one we employ, have reliable power in samples of moderate size.

The existing literature on FAANG stocks focuses primarily on their performance and technical analysis. De Almeida (2020) demonstrated that standard technical analysis indi-

cators (Ichimoku, MACD, RSI) yield actionable signals for FAANG stocks, confirming that these stocks are amenable to rigorous empirical analysis. Sen and Chakrabarti (2023) document risk, volatility, and bubble episodes in FAANG portfolios. Saleem et al. (2023) examine FAANG stocks alongside gold and

Islamic equity during COVID-19, providing evidence of their elevated systematic risk during the pandemic period. Despite this growing body of work, no prior study has systematically examined the co-jump dynamics of FAANG stocks as a group, and this gap motivates the present analysis.

3 DATA AND METHODOLOGY

3.1 Data

This study uses daily adjusted closing price and trading volume data for five leading technology stocks, collectively known as the FAANG stocks: Facebook, Apple, Amazon, Netflix, and Google. Data were obtained from Yahoo Finance (<https://finance.yahoo.com>), covering the period from May 18, 2012, through April 1, 2026. The sample period was determined by the earliest date of simultaneous data availability for all five stocks. Facebook completed its IPO on May 18, 2012, making this the natural start date. The 13-year window encompasses seven distinct market regimes: the post-financial crisis recovery (2012–2014), the 2015–2016 equity correction, the 2018 US–China trade war, the COVID-19 pandemic shock (2020), the post-pandemic inflation and rate-hike cycle (2021–2023), the AI-driven technology rally (2023–2024), and the renewed market volatility driven by global trade policy uncertainty (2025–2026). This breadth ensures that our findings are not specific to any single market environment.

Our empirical analysis relies on log returns, multiplied by 100 to simplify interpretation. To verify that each return series satisfies the stationarity condition required for GARCH-based conditional variance modeling, we apply the Augmented Dickey-Fuller (ADF) test. The results, summarized in Tab. 1, confirm that all return series are stationary at the 1% significance level, indicating their stability over time. All p -values below 0.0001 are reported as ‘< 0.0001’ to avoid the misleading implication of an exact zero probability.

Tab. 1 also details key statistical properties of the returns. Netflix showed the highest average daily return (0.0013), followed by Amazon and Google (0.0009 each), while Apple and Facebook had the lowest mean return (0.0008 each). Netflix displayed the highest volatility (standard deviation = 0.029), while Apple had the lowest (0.0178). The skewness values were mostly negative, indicating returns tended toward losses, except for Amazon and Google, which had slight positive skewness. Significant excess kurtosis is evident for all

Tab. 1: Daily return statistical features (May 2012 – April 2026)

	Apple	Amazon	Google	Facebook	Netflix
Mean	0.0008	0.0009	0.0009	0.0008	0.0013
Max.	0.1426	0.1322	0.1506	0.2594	0.3522
Min.	−0.1377	−0.1514	−0.1237	−0.3064	−0.4326
Std. Dev.	0.0178	0.0202	0.0173	0.0250	0.0290
Skewness	−0.2020	0.0304	0.1308	−0.4071	−0.5058
Kurtosis	9.6626	8.9532	9.7046	24.4088	32.4957
p -value ADF test	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
p -value ARCH-LM test	< 0.0001	< 0.0001	< 0.0001	0.0090	0.0025

Note: p -values below 0.0001 reported as ‘< 0.0001’ (blue) per revised reporting convention.

stocks, notably Netflix and Facebook, indicating a higher frequency of extreme price movements than under a normal distribution. The ARCH-LM test results (Engle, 1982) indicate conditional heteroscedasticity across all return series, confirming that a GARCH specification is appropriate.

Tab. 2 reports the Pearson correlation matrix of FAANG stock returns, ranging from 0.312 (Netflix and Apple) to 0.610 (Google and Amazon). Amazon is found to have a strong positive correlation with Google (0.610), while the correlation between Apple and Netflix is the weakest (0.312). These correlations imply limited diversification benefit within FAANG portfolios, particularly during market turbulence.

3.2 Methodology

This study investigates the presence of jumps and co-jumps in the returns of FAANG assets. Drawing on the conceptual framework of Laurent et al. (2016), we implement a simplified semi-parametric jump detection procedure. Unlike the original Laurent et al. (2016) approach, which employs a Bounded Innovation Propagation (BIP-GARCH) specification to prevent jump contamination of volatility estimates, we use a standard GARCH (1,1) model for computational tractability. This simplification is motivated by our primary objective of detecting jumps rather than precisely estimating the volatility process, and is acknowledged as a limitation. Our analysis proceeds in two main stages: jump detection in individual asset returns, followed by co-jump analysis across assets.

3.2.1 Testing for Jumps

We begin by estimating the conditional mean of the asset returns using either an autoregressive AR (p) process or a simple OLS with a time trend, defined as follows:

Step 1: Estimation of Conditional Mean

The conditional mean μ_t . The asset returns are estimated using either an autoregressive AR (p) model or a simple time trend with ordinary least squares (OLS). The model is described as follows:

$$r_t = \mu_t + \sum_{i=1}^p \zeta_i r_{t-i} + \epsilon_t, \quad (1)$$

where r_t represents the asset return at a time t , the μ_t is the conditional mean, ζ_i refers to the autoregressive coefficients for the lag i and lastly ϵ_t is the error term.

Using Time Trend (OLS) the equation is written as follows:

$$\mu_t = b_0 + b_1 t, \quad (2)$$

where b_0, b_1 refer to the parameters of the time trend estimated via OLS, and the residuals are calculated using the following formula:

$$\text{ar_resid} = r_t - \mu_t. \quad (3)$$

Step 2: Conditional Volatility Modeling

In this step, we model the conditional volatility (σ_t^2) using a standard GARCH (q, q) model:

$$\sigma_t^2 = \omega + \sum_{i=1}^q \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^q \beta_i \sigma_{t-i}^2, \quad (4)$$

$$i = 1, 2, \dots, q,$$

Tab. 2: Pairwise Pearson Correlation Matrix of FAANG Returns

	Apple	Amazon	Google	Facebook	Netflix
Apple	1				
Amazon	0.490	1			
Google	0.539	0.610	1		
Meta	0.428	0.519	0.529	1	
Netflix	0.312	0.450	0.384	0.351	1

Note: Sample period May 18, 2012 – April 1, 2026. All correlations are statistically significant at $p < 0.01$.

where σ_t^2 represents the conditional variance at time t , ω refers to constant, α_i refers to coefficients for lagged squared residuals (ϵ_{t-i}^2), β_i represents coefficients for lagged variances (σ_{t-i}^2).

Then, the conditional standard deviation is calculated as follows:

$$\sigma_t = \sqrt{\sigma_t^2} \quad (5)$$

While the original Laurent et al. (2016) method includes a leverage effect term in the GARCH model, represented as $\theta I_{t-1} \epsilon_{t-1}^2$, we chose to omit this component for computational simplicity, given that our primary goal is to detect jumps rather than precisely estimate volatility using the GJR-GARCH model.

Standardized Returns and Jump Detection

Next, the standardized returns ($\tilde{J}_t$) are calculated as:

$$\tilde{J}_t = \frac{r_t - \mu_t}{\sigma_t} \quad (6)$$

Jumps are detected when the absolute value of the standardized return exceeds a threshold (λ), set at 3.0:

$$I_t = \begin{cases} 1, & \text{if } |\tilde{J}_t| > \lambda, \\ 0 & \text{otherwise,} \end{cases} \quad (7)$$

where I_t is the jump indicator variable.

3.2.2 Co-Jumping Analysis

After identifying individual asset jumps, we analyze the co-occurrence of jumps across the FAANG assets. We use two complementary methods: a co-exceedance rule and logistic regression. The attribution of these methods follows the co-jump literature (Dungey and Hvozdyk, 2011; Bouri et al., 2020; Clements and Liao, 2017) rather than any single reference; the threshold-based approach is not to be confused with the volatility forecasting framework of Ma et al. (2019).

Co-Exceedance Method

A co-jump event is defined as any trading day on which at least $n = 3$ of the five FAANG

assets simultaneously exhibit a detected jump:

$$\begin{aligned} \sum I(\text{Jump}_{i,t} > 0) &= \\ &= \begin{cases} n_{\text{cojump}}, & \text{if } n \geq 3, \\ 0 & \text{otherwise,} \end{cases} \end{aligned} \quad (8)$$

where $I(\text{Jump}_{i,t} > 0)$ is an indicator of a jump in the asset i at time t , n refers to the threshold for simultaneous jumps ($n = 3$), and n_{cojump} counts of co-jump days. This threshold-based co-exceedance rule (Equation 8) constitutes our primary co-jump definition. The threshold $n = 3$ requires a majority of FAANG assets to jump simultaneously, reducing spurious co-jump detection from unrelated idiosyncratic events while remaining sensitive to systemic shocks. We also generate a detailed co-jump table containing individual jump indicators for all assets on co-jump days.

Logistic Regression

To further characterize co-jump behaviour, we estimate logistic regressions where the jump indicator for each asset is modelled as a function of contemporaneous jump indicators for the other assets:

$$\begin{aligned} \log \left(\frac{P(Y_t = 1 | X_t)}{1 - P(Y_t = 1 | X_t)} \right) &= \\ &= \beta_0 + \sum_i \beta_i X_{i,t} + \epsilon_t, \end{aligned} \quad (9)$$

where Y_t is the binary jump indicator for the target asset, and $X_{i,t}$ are jump indicators for peer assets. We note explicitly that, because this regression is estimated on contemporaneous indicators, the results capture co-movement associations rather than causal or lead-lag dynamics.

Co-Jump Network Graph

Co-jump interdependencies are represented through a weighted network structure, where each node $i \in \mathbb{N}$ corresponds to a FAANG asset. Edge weights are defined as

$$w_{ij} = \sum_{t=1}^T I_t(i) I_t(j), \quad (10)$$

where $I_t(i)$ is a binary indicator equal to one if the asset i experiences a jump at a time t , and zero otherwise. This specification captures the total number of synchronous jump occurrences between asset pairs. Node size is scaled by the marginal jump intensity, $\sum_{t=1}^T I_t(i)$, providing a visual proxy for individual asset jump activity. Edge thickness and color intensity are mapped to w_{ij} , with higher values indicating stronger co-jump linkages. The viridis colormap is employed to ensure perceptual uniformity and robustness to color-vision deficiencies.

3.3 Jump Determinants: Macro Covariates

To relate jump occurrences to observable market conditions, a binary response model is estimated separately for each FAANG asset. The dependent variable $I_{i,t} \in \{0, 1\}$ denotes the daily jump indicator defined in Section 3.2.1. The empirical specification is given by

$$\begin{aligned} \log\left(\frac{P(I_{i,t} = 1)}{1 - P(I_{i,t} = 1)}\right) = \\ = \gamma_0 + \gamma_1 \text{VIX}_t + \gamma_2 R_t^{\text{SP}} + \\ + \gamma_3 D_t^{\text{COVID}} + \gamma_4 D_t^{\text{TRADE}} + u_{i,t}, \end{aligned} \quad (11)$$

where VIX_t denotes the daily closing level of the CBOE Volatility Index, and R_t^{SP} is

the contemporaneous log return on the S&P 500, computed as the first difference of log closing prices. The indicator D_t^{COVID} equals one over March 1 – June 30, 2020, capturing the acute phase of the COVID-19 pandemic market disruption, while D_t^{TRADE} equals one over July 1 – December 31, 2018, corresponding to the escalation of the US–China trade war. The sample comprises 3,485 daily observations per asset, fully aligned with the jump indicator series.

Equation (11) is estimated via maximum likelihood. Coefficients are reported in three complementary forms to enhance interpretability: (i) log-odds estimates with associated p -values; (ii) odds ratios, computed as $\exp(\hat{\gamma}_k)$, capturing the multiplicative change in the odds of a jump for a one-unit increase in the covariate; and (iii) average marginal effects (AME), defined as

$$\text{AME}_k = \frac{1}{T} \sum_{t=1}^T \hat{p}_{i,t} (1 - \hat{p}_{i,t}) \hat{\gamma}_k, \quad (12)$$

where $\hat{p}_{i,t} = P(I_{i,t} = 1 \mid X_t)$. This formulation avoids reliance on a scalar approximation and ensures consistency with the nonlinear nature of the logit model. Estimation results are reported in Tab. 6 (Section 4.3).

4 RESULTS AND DISCUSSION

4.1 Detection of Jumps and Chronological Trends

This study adopts a standardized residual approach based on Laurent et al. (2016), utilizing a GARCH(1,1) conditional volatility framework to detect jump behavior in FAANG stock returns. As illustrated in Fig. 1 and reported in Tab. 3, there is relative consistency in total jump counts across FAANG assets (42 to 48 jumps over 2012–2026), indicating that jumps are not concentrated in any single stock. However, jump distributions vary significantly from asset to asset and year to year.

In 2018, a relatively high jump count was witnessed in Google, Apple, Facebook, and Netflix stocks (5, 4, 4, 4, respectively), followed by Amazon (2), implying considerable market volatility for Google, Apple, Facebook, and Netflix. A possible reason is the heightened uncertainty about the US–China trade war and its disproportionate impact on technology sector valuations.

During the COVID-19 uncertainty period (2020), a considerable increase in jumps was witnessed across all FAANG stocks: Facebook and Amazon (5 each), and Apple, Netflix, and Google (4 each). In 2021, an obvious decline in stock jumps was observed. However, 2022

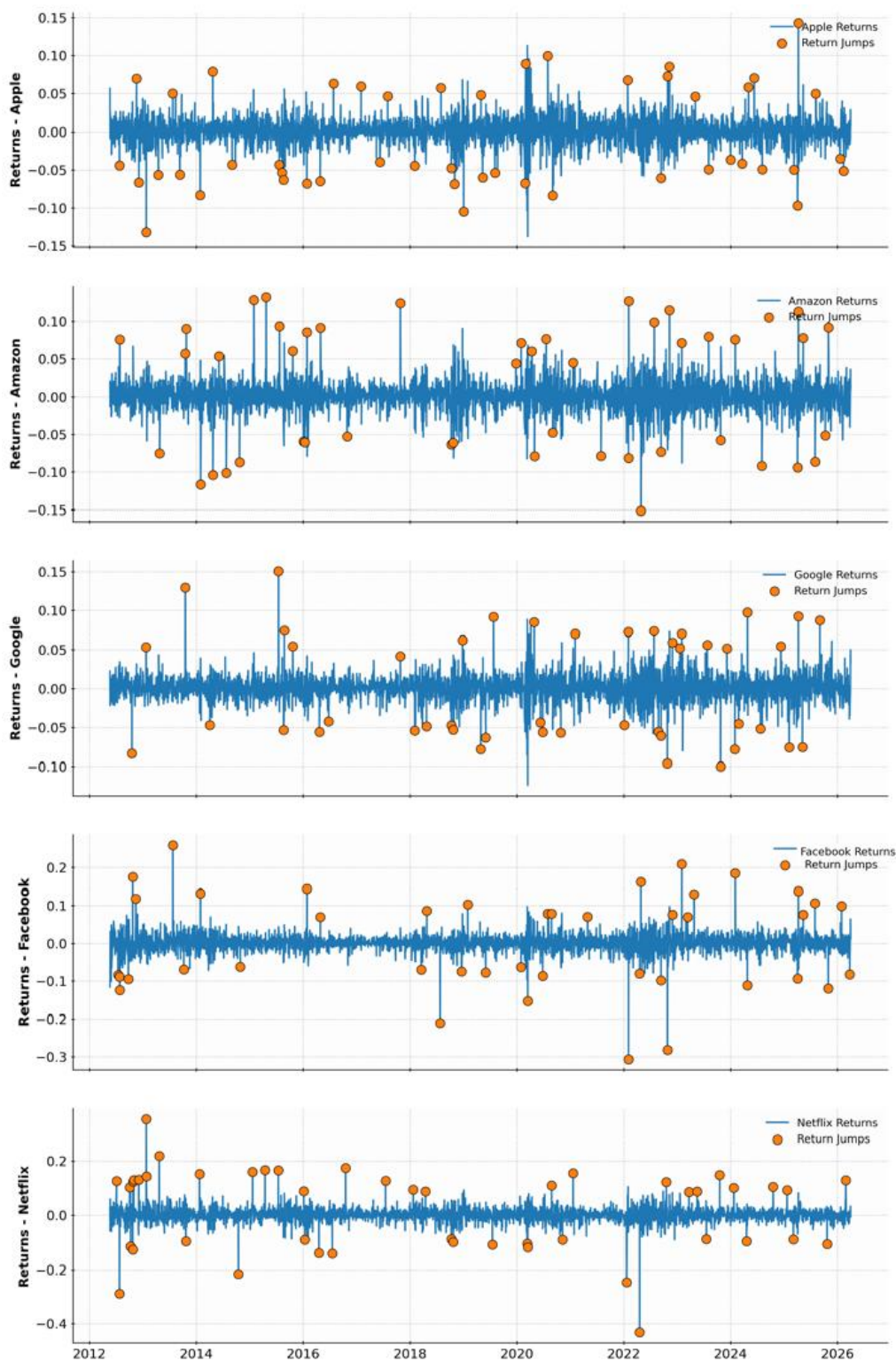


Fig. 1: Jump plots on the FAANG daily return

Tab. 3: Jump detection results by year and asset

	Panel A: Number of Jumps						Panel B: % Days with Jumps				
	Apple	Amazon	Google	Facebook	Netflix	Sum	Apple	Amazon	Google	Facebook	Netflix
2012	3	1	1	6	8	19	1.95	0.65	0.65	3.90	5.19
2013	4	3	2	2	4	15	1.59	1.19	0.79	0.79	1.59
2014	3	5	1	2	2	13	1.19	1.98	0.40	0.79	0.79
2015	3	4	4	0	3	14	1.19	1.59	1.59	0.00	1.19
2016	3	5	2	2	5	17	1.19	1.98	0.79	0.79	1.98
2017	3	1	1	0	1	6	1.20	0.40	0.40	0.00	0.40
2018	4	2	5	4	4	19	1.59	0.80	1.99	1.59	1.59
2019	4	1	3	2	1	11	1.59	0.40	1.19	0.79	0.40
2020	4	5	4	5	4	22	1.58	1.98	1.58	1.98	1.58
2021	0	2	1	1	1	5	0.00	0.79	0.40	0.40	0.40
2022	4	6	7	6	3	26	1.59	2.39	2.79	2.39	1.20
2023	2	3	5	3	4	17	0.80	1.20	2.00	1.20	1.60
2024	5	2	5	2	3	17	1.98	0.79	1.98	0.79	1.19
2025	4	6	4	5	3	22	1.60	2.40	1.60	2.00	1.20
2026	2	0	0	2	1	5	3.23	0.00	0.00	3.23	1.61
Total Jumps	48	46	45	42	47	228	1.38	1.32	1.29	1.20	1.35

Note: sample period May 18, 2012 – April 1, 2026

witnessed an increase in jumps for Google (7) and Amazon and Facebook (6 each), consistent with the impact of the Federal Reserve’s aggressive rate-hike cycle on high-growth technology valuations.

These findings are broadly consistent with jump frequency estimates reported for large-cap US equities in Johnson et al. (2022), who document average annual jump rates of approximately 3–5 events for S&P 500 constituents. Our results corroborate Bouri et al. (2020) in identifying macro uncertainty as a primary driver of elevated jump activity. The network analysis extending Clements and Liao (2017), who demonstrate that high-capitalization constituents disproportionately originate index co-jumps.

4.2 Co-Jump Analysis

The logistic regression results in Tab. 4 reveal that jump activity across FAANG stocks is positively correlated on a contemporaneous basis. We emphasize that, because the logistic regression is estimated on contemporaneous jump

indicators, these results capture co-movement patterns rather than causal dynamics. For instance, the Google coefficient for predicting jumps in Amazon (2.43) and the Facebook coefficient for predicting jumps in both Amazon (2.52) and Google (1.58) are statistically significant at the 1% level, indicating that days on which these assets jump are significantly more likely to also be days on which their FAANG peers jump. No significant coefficients are found for the impact of Facebook on Apple, or Netflix on Apple or Google, suggesting some independence in jump behavior for these pairs.

Applying the co-exceedance rule (Tab. 5) identifies 6 co-jump days over 2012–2026, confirming their rarity. Two occurred in 2018 (trade war period), one in 2022 (rate shock period), one in 2023, and two in April 2025 (renewed global trade policy uncertainty). This co-jump clustering around specific macro stress periods is consistent with Baruník and Fišer (2019), who show that Treasury yield curve co-jumps are predominantly driven by monetary policy announcements, and with Bouri et al. (2020), who document that cryptocurrency co-jumps

Tab. 4: Logistic regression results — co-jump associations

	Apple	Amazon	Google	Facebook	Netflix
Amazon		2.00***	2.44***	2.53***	1.42**
Apple	1.98***		1.34**		
Google	2.43***	1.34**		1.62***	
Facebook	2.52***		1.58***		1.52**
Netflix	1.29*			1.54**	

Notes: *, **, *** denote significance at 10%, 5%, 1% levels. Coefficients are log-odds. Logistic regression estimated on contemporaneous jump indicators.

coincide with elevated market-wide uncertainty and trading volume. Our result suggests the same mechanism applies to FAANG equities: co-jumps are not randomly distributed but cluster at moments of economy-wide regime shifts.

The network graph (Fig. 2 shows Amazon as the most central node, appearing in all 6 co-jump events, with the strongest pairwise linkage to Google and Facebook (9 co-jump days) and Amazon-Apple and Amazon-Netflix (7 and 4, respectively). Netflix is the most peripheral node, co-jumping with other FAANG assets on only 2 occasions, reflecting lower co-jump connectivity. These centrality patterns extend the findings of Clements and Liao (2017), who demonstrate that high-capitalization index constituents disproportionately originate co-jumps; Amazon and Google, as the two largest FAANG stocks by market cap for most of our sample, play an analogous role within the FAANG group.

4.3 Jump Determinants: Macroeconomic Analysis

Tab. 6 reports the odds ratios from the macro-covariates logistic regression (Equation 11), linking the daily jump indicator for each FAANG stock to the VIX level, the S&P 500 return, and two event dummies for the COVID-19 pandemic and the US-China trade war.

Three findings stand out. First, the VIX level is a positive and significant predictor of jump probability for four of the five FAANG stocks (Apple, Amazon, Google, Facebook), with Facebook showing the strongest sensitivity (OR = 1.078, $p < 0.001$). Netflix is the exception, consistent with its more idiosyncratic

return profile documented in the jump network analysis (Section 4.2), where it also emerges as the most peripheral node. This VIX result reinforces the paper’s central finding that FAANG jumps are not random but are tied to aggregate market conditions, consistent with the same macro environment that drives co-jump clustering.

Second, the S&P 500 return is negatively associated with jump probability for Apple and Netflix, confirming that jumps in these two stocks are concentrated on down-market days. This downside asymmetry is consistent with the negative skewness reported for all FAANG stocks in Tab. 1 and supports the interpretation that extreme price movements in FAANG stocks are predominantly losses rather than gains.

Third, neither the COVID-19 dummy nor the trade war dummy reaches statistical significance for any asset, once VIX and market returns are controlled for. This does not mean these events had no effect on jump activity, the raw jump counts in Tab. 3 clearly show elevated activity in 2018 and 2020. Rather, it confirms that the mechanism was macroeconomic: both episodes worked through elevated VIX and sharply negative market returns, channels already captured by γ_1 and γ_2 . This is consistent with the co-jump analysis in Section 4.2, which identified macro stress periods as the driver of co-jump clustering rather than firm-specific factors.

Taken together, these results provide direct empirical support for the paper’s core argument: FAANG jump and co-jump activity is systematically linked to observable macro conditions, with VIX serving as the primary early-

Tab. 5: The co-jumping results through Ma et al.’s (2019) approach

	Jumps-Apple	Jumps-Amazon	Jumps-Google	Jumps-Facebook	Jumps-Netflix	Number of jumps ≥ 3
10/10/2018	1	1	1	0	1	4
24/10/2018	0	1	1	0	1	3
13/9/2022	1	1	1	1	0	4
2/2/2023	0	1	1	1	0	3
3/4/2025	1	1	0	1	0	3
9/4/2025	1	1	1	1	0	4
Total number of co-jumps:						6

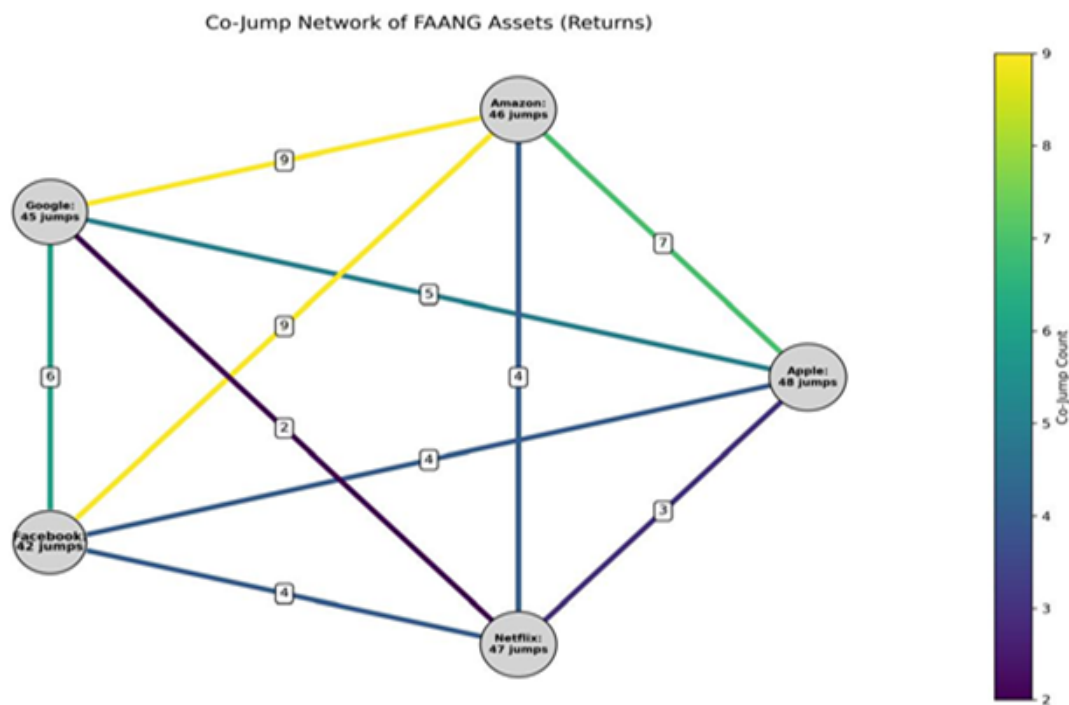


Fig. 2: The Co-Jump Network of FAANG stocks

Tab. 6: Jump Determinants – Odds Ratios $[\exp(\hat{\gamma})]$

Covariate	Apple	Amazon	Google	Facebook	Netflix
VIX (level)	1.043*	1.044*	1.039*	1.078***	1.024
S&P 500 return	0.000*	0.000	0.001	2.595	0.000***
COVID dummy (2020 Q1–Q2)	0.142	0.404	0.993	0.203	0.327
Trade war dummy (2018 H2)	1.746	1.222	2.020	1.403	1.138

Notes: ***, **, * denote significance at 1%, 5%, 10%. Bold = significant. Odds ratios below 1 indicate a negative association with jump probability.

warning indicator. Portfolio managers with concentrated FAANG exposures can treat rising VIX levels as a signal for heightened jump risk, complementing the static jump-detection framework presented in Sections 3.2 and 4.1.

4.4 Systematic Patterns and Portfolio Implications

Several systematic patterns emerge from the jump and co-jump analysis, from which clear investment implications can be derived. First, jump activity is strongly counter-cyclical: the highest annual jump frequencies consistently coincide with macro stress years (2018, 2020, 2022, 2025), with 2022 recording the highest percentage of jump days across the full sample (Tab. 3, Panel B). This counter-cyclicity implies that FAANG stocks offer the least return predictability precisely when global risk appetite deteriorates.

Second, jumps in FAANG stocks are predominantly negative in direction: across all five assets, approximately 58–67% of detected jumps correspond to large negative returns (based on the sign of the standardized return

Jt at jump dates). This downside asymmetry implies that jump risk in FAANG stocks is disproportionately a risk of sudden, large losses rather than gains.

Third, the six co-jump events (Tab. 5) all coincide with identifiable systemic shocks, namely the 2018 trade war technology sector sell-off, the 2022 macroeconomic rate shock, and the renewed global trade policy uncertainty in April 2025, rather than any firm-specific news. This confirms that FAANG co-jumps are macro-driven rather than idiosyncratic, meaning that within-FAANG diversification does not protect against co-jump events.

For portfolio managers, these three patterns jointly imply: (1) FAANG-only portfolios provide negligible diversification benefit during the episodes of joint extreme loss that matter most; (2) dynamic hedge strategies using VIX-linked instruments (e.g., VIX call options) may provide more reliable tail-risk protection than passive diversification; and (3) the centrality of Amazon and Google in the co-jump network suggests that these two stocks warrant higher risk-factor loadings in multi-factor risk models for FAANG portfolios.

5 CONCLUSION

This paper provides the first comprehensive analysis of jump and co-jump behavior across all five FAANG stocks over the 2012–2026 period. The FAANG group, with a combined market capitalization of approximately \$9 trillion, represents the most concentrated cluster of systemically important equities in contemporary financial markets, making an understanding of their joint extreme price dynamics essential for both practitioners and regulators. Results demonstrate the presence of jump and co-jump activity within the FAANG stocks. The majority of stock jumps occur during periods of large market instability, indicating FAANG stocks' sensitivity to global shocks. Amazon emerges as the most central node in the co-jump network, appearing in all six co-jump events, with the strongest pairwise linkage to Google and Facebook (9 co-jump days), confirming

Amazon's role as the primary vector of shock propagation within the FAANG cluster.

The policy and portfolio implications are direct. Because FAANG co-jumps are macro-driven (clustering around the 2018 trade war, the 2022 rate shock, and the April 2025 trade policy shock), within-FAANG diversification offers negligible protection during joint extreme loss events. Portfolio managers should consider supplementing FAANG holdings with assets that are uncorrelated with macro uncertainty (e.g., short-duration bonds, volatility strategies) and should treat Amazon as the highest-centrality risk node in any FAANG-heavy portfolio, given its participation in all six co-jump events. Policymakers monitoring systemic risk should note that co-jumps in FAANG stocks, given their dominant index weights, represent potential transmission chan-

nels from idiosyncratic technology sector shocks to broader market instability. The new macro-determinants analysis confirms that VIX is a consistent leading indicator of FAANG jump probability, suggesting that real-time volatility monitoring can serve as an early-warning system for elevated jump risk.

This study has several limitations that should inform the interpretation of results. First, we employ a standard GARCH(1,1) for conditional variance estimation rather than the BIP-GARCH of Laurent et al. (2016), which is designed to be robust to jump contamination. This may result in some upward bias in volatility estimates on jump days, potentially affecting the standardized residuals used for jump detection. Future work should implement the full BIP-GARCH specification to assess the sensitivity of jump counts to this modeling choice. Second, our analysis is based on daily data;

high-frequency intraday data would allow more precise jump detection and enable the identification of intraday co-jump timing. Third, our sample of five stocks, while motivated by their systemic importance, precludes generalizations to other technology stocks or other markets.

Future studies could incorporate market sentiment, macro announcement effects, and other market measures to determine external factors that stimulate FAANG co-jumps. Decomposing jumps into positive and negative components (asymmetric jump analysis) would provide further insight into the asymmetric risk profile documented here. Extending the analysis to other technology stock clusters internationally (e.g., Chinese BAT stocks: Baidu, Alibaba, Tencent) would provide a broader perspective on whether co-jump centrality is a universal property of dominant technology firms or specific to the US market structure.

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7 ANNEX

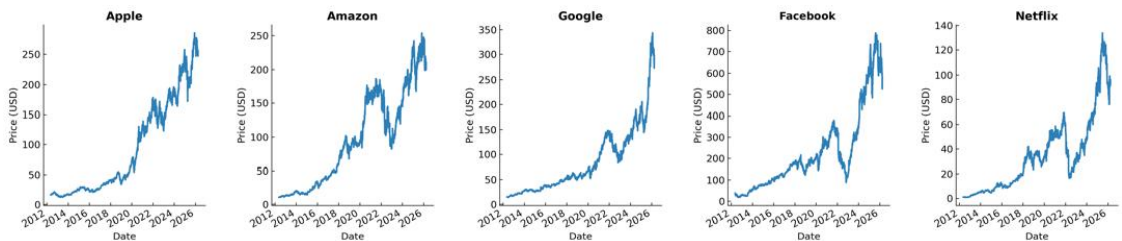


Fig. 3: Plots of price levels of FAANG stocks

Declaration of generative AI and AI-assisted technologies:

Artificial intelligence tools (OpenAI's ChatGPT, GPT-5 model) were employed to assist in refining the English language, improving sentence clarity, and suggesting structural enhancements for the manuscript. The use of AI was limited to linguistic and stylistic improvements; all core ideas, theoretical frameworks, data analyses, interpretations, and conclusions are the original work of the authors. The authors have thoroughly reviewed and validated all AI-assisted edits to ensure accuracy and academic integrity.

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MICROCERTIFICATES SMART CONTRACT PERFORMANCE ON PROOF-OF-AUTHORITY BLOCKCHAIN

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ABSTRACT

Permissioned blockchains that use proof-of-authority (PoA) consensus mechanisms are becoming more popular for business and institutional applications. However, there is a big gap in the academic literature about how well these systems work in real situations, like when they're used with smart contracts on live production networks. Existing blockchain credential platforms, including Blockcerts and the European Blockchain Services Infrastructure (EBSI), have shown that these platforms can work. However, there aren't many published examples. It's important to remember that these examples are often based on test environments, not real-world operations. This paper aims to address this gap by presenting a comprehensive, statistically based performance analysis of a smart contract-based micro-credentialing system utilized on the Bloxberg PoA blockchain. The entire certificate lifecycle, including issuance, revocation, and verification, is tested with controlled stress tests that are repeated many times at each load level. The process involves assigning workloads to the live network and then collecting key performance indicators (KPIs). The key performance indicators (KPIs) mentioned earlier include things like gas consumption with opcode-level breakdown, how long transactions take with standard deviations and 95% confidence intervals, and logical throughput. The findings show a clear trade-off in performance metrics. The application can verify things quickly (118 milliseconds on average), which makes it suitable for real-time use. However, the atomic issuance model has throughput bottlenecks, reaching a saturation point of about 4.2 transactions per second. It also demonstrates cost inefficiencies due to the repetition of base-fee overhead. A thorough review of how gas is used is also provided.

KEY WORDS

blockchain, proof-of-authority, smart contracts, bloxberg, ethereum virtual machine, micro-credentials, digital certificates, performance benchmarking, verifiable credentials

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1 INTRODUCTION

Blockchain technology has evolved from public, permissionless systems like Ethereum and Bitcoin to private, permissioned ledgers designed for use by organizations and companies. Academic credentialing applications often require features that are often missing from public systems. These features include higher performance, more predictable transaction costs, improved privacy, and stronger governance models (Alsobhi et al., 2023). There are several blockchain-based credential platforms that have been created to meet this need. The Blockcerts open standard provides a framework for issuing and verifying blockchain-anchored credentials (Blockcerts, 2016). The European Blockchain Services Infrastructure (EBSI) operates a multi-chain infrastructure for cross-border credential verification (European Commission, 2021). The Europass Digital Credentials Infrastructure (EDCI) offers a European Commission-backed issuance pipeline that complies with the W3C Verifiable Credentials standard (Tan et al., 2023). These systems show that it is possible to create a system for credentialing that is spread out and not controlled by a central authority. However, there is not a lot of real-world data about how well these systems work.

The PoA consensus algorithm is widely used in institutional blockchain contexts. Unlike Proof-of-Work (PoW), which relies on computationally expensive cryptographic puzzle-solving to select block producers in a competitive, energy-intensive lottery, PoA delegates block creation to a pre-approved set of authenticated validators through a deterministic rotation schedule (Azbeg et al., 2021; Cao et al., 2020; Zheng et al., 2017).

Although PoA networks are becoming more popular, there is still not a lot of real-world proof of how well they work under real smart-contract conditions on live networks. The study that inspired this work suggested a system for issuing digital microcertificates on the Bloxberg blockchain. However, the study also mentioned that the evaluation was “mostly qualitative and descriptive” and did not include “large-scale use or performance measurements” (Zák拉斯ník

et al., 2024). A lot of the current blockchain performance literature is based on analyses of private testnets, simulated environments, or theoretical modeling (Fan et al., 2020). These methods are useful, but they don’t capture everything about a live production network. A lot of things can affect the results, like the behavior of a set of validator nodes that are spread out, the load from other applications, and the network latency in the real world. Important benchmarking frameworks like BlockBench (Dinh et al., 2017) and Hyperledger Caliper (Fan et al., 2020) have mostly been used with Hyperledger Fabric and Ethereum testnets. But they have not been used with live PoA consortium networks that handle real credential workloads. To connect the dots between PoA’s practical performance and its theoretical potential, we need real-world evidence from production settings (Zák拉斯ník et al., 2024).

By providing a fully functional system for issuing, revoking, and verifying trusted micro-credentials, this paper seeks to close this gap. We describe the architecture of the system, which combines the Bloxberg PoA blockchain with modern web technologies, and evaluate the system in a real deployment. We identify the performance trade-offs of a one-by-one issuance model, benchmark the complete certificate lifecycle (issuance, revocation, and read-only verification), and test the application programming interface (API) endpoints to assess whether the solution meets the reliability requirements of end users.

The most important contributions of this work are as follows:

1. We provide a statistical analysis of the production Bloxberg PoA network’s performance under different smart-contract workloads, reporting means, standard deviations, and 95% confidence intervals across multiple experimental repetitions for each load level.
2. We look at the entire process of issuing, revoking, and verifying certificates. This gives us a better understanding of how well the system is working.

3. We present a detailed breakdown of the cost of a granular gas at the EVM opcode level (base cost, SSTORE, calldata, and execution overhead). We also do a comparative economic analysis that puts the per-certificate costs into context and shows how much can be saved by batching.
4. We offer a stress-testing methodology for smart contracts that can be used repeatedly. It works on live permissioned networks. It specifies the workload generation procedure, data collection protocol, outlier filtering, and statistical analysis steps. Other researchers can adapt the approach for further research (Menascé et al., 2004).

You can find the test harness source code at <https://github.com/MENDELUI-PEF-UI-SMART/bloxberg-benchmark>.

The remainder of this paper is organized as follows: Section 2 summarizes the background research on proof-of-authority, blockchain-based credential systems, benchmarking frameworks, and EVM gas mechanics. Section 3 describes the architecture of the implemented micro-credentialing system. Section 4 details the experimental design, including the scenarios, schedule, and statistical approach. Section 5 presents the empirical findings and performance analysis. Section 6 discusses the results in the context of existing literature, economic implications, and alternative scalability strategies.

2 BACKGROUND AND RELATED WORK

This section explains the theoretical foundations needed to understand the experimental design and interpret the results. It looks at the PoA consensus mechanism, existing blockchain-based credential systems, benchmarking frameworks and performance metrics, and EVM gas mechanics.

2.1 Blockchain and Proof-of-Authority

The Proof-of-Authority consensus model is designed for efficiency, high transaction throughput, fast and predictable block confirmation, and minimal energy consumption. Unlike Proof-of-Work, where miners compete by solving cryptographic puzzles (searching for preimages under a difficulty target that changes over time), PoA gives a set of pre-approved, identity-verified validators the job of creating blocks. These validators work in a round-robin or similar rotation schedule (Azbeg et al., 2021; Cao et al., 2020; Zheng et al., 2017). This eliminates the computational waste of PoW while providing sub-minute block intervals that are well suited to institutional applications.

Network security in PoA relies on the assumption that validators are trusted, identifiable entities who are deterred from malicious

behavior by the risk of real-world reputational harm (Azbeg et al., 2021). An attack on the network, such as a 51% attack, would require an adversary to compromise a majority of these known validator nodes (Zheng et al., 2017). This model introduces a degree of centralization, but it provides strong accountability because malicious actions can be attributed directly to the responsible validator (Azbeg et al., 2021).

The Bloxberg network, which serves as the production environment for this study, is an implementation of this model. It is a global, permissioned blockchain infrastructure established for the scientific community and operated by a consortium of research organizations that serve as validator nodes (Kleinfurher and Vengadasalam, 2024).

2.2 Blockchain-Based Credential Systems

We situate our system relative to three prominent initiatives. Blockcerts, originally developed at MIT Media Lab, provides an open standard for anchoring credential hashes on public blockchains (Bitcoin and Ethereum). It follows a minimalist on-chain model: only the Merkle root of a credential batch is written

to the ledger, while the full credential payload is stored off-chain as a JSON-LD document conforming to the W3C Verifiable Credentials (VC) data model (Blockcerts, 2016). Published evaluations of Blockcerts focus on interoperability and portability rather than throughput or cost analysis.

The European Blockchain Services Infrastructure (EBSI), operated by the European Commission and EU Member States, provides a multi-chain infrastructure for cross-border credential verification using Verifiable Credentials anchored on a Hyperledger Besu-based permissioned network (European Commission, 2021). EBSI integrates with the European Self-Sovereign Identity Framework (ESSIF) and supports Decentralized Identifiers (DIDs) compliant with the W3C DID standard. Although EBSI documentation describes conformance testing, peer-reviewed performance benchmarks from its production environment have not yet been published.

The Europass Digital Credentials Infrastructure (EDCI), backed by the European Commission, offers an issuance pipeline for digitally signed, machine-readable credentials. EDCI relies on qualified electronic signatures (eIDAS-compliant) rather than blockchain anchoring for tamper evidence, though its architecture supports optional blockchain notarization. Practical challenges in cross-institutional adoption of these systems, including governance fragmentation and interoperability friction, have been documented by Tan et al. (2023).

Our system shares the hybrid on-chain/off-chain architecture and W3C VC compatibility with these platforms but differs in its deployment on the Bloxberg PoA network, its focus on quantitative performance analysis, and its emphasis on the gas cost economics of state-modifying credential operations. To the best of our knowledge, no prior study has published statistically rigorous throughput, latency, and gas-cost benchmarks from a live deployment of a blockchain-based credential system.

2.3 Performance Benchmarking in Blockchain Systems

Systematic evaluation of blockchain performance is essential for understanding system capabilities and identifying bottlenecks. Following the taxonomy of Cao et al. (2020), such evaluations typically rely on a set of key performance indicators (KPIs):

- *Throughput*: Commonly measured in transactions per second (TPS), throughput quantifies the rate at which the network processes and confirms transactions. However, when comparing different operational patterns (e.g., single versus bulk operations), raw TPS can be misleading. In such cases, an application-level metric, such as logical operations per second (e.g., certificates issued per second), provides a more meaningful basis for comparison (Fan et al., 2020).
- *Latency*: The time elapsed from the moment a transaction is submitted by a client to its inclusion in a confirmed block on the ledger. It represents the user-perceived delay for a transaction to be accepted by the network (Fan et al., 2020).
- *Time-to-finality (TTF)*: The time required for a transaction to be considered irreversible. In PoW networks, finality is probabilistic and typically requires multiple block confirmations. In PoA networks, by contrast, consensus is deterministic and can be achieved much faster, sometimes within a single block confirmation (Cao et al., 2020).
- *Scalability*: The system's ability to maintain consistent performance (throughput and latency) as the transaction workload increases or as the number of participating nodes grows (Zheng et al., 2017).

To measure these KPIs, several academic and open-source benchmarking frameworks have been developed. BlockBench (Dinh et al., 2017) provides a comparative evaluation framework supporting Ethereum, Hyperledger Fabric, and Parity (now OpenEthereum); it defined the YCSB-style macro-benchmarks that subsequent studies have adopted. Hyperledger Caliper (Fan et al., 2020) offers a modular,

plugin-based architecture for deploying configurable workloads on multiple blockchain backends. Gromit (Fan et al., 2020) extends these approaches with fine-grained bottleneck analysis. Performance studies on permissioned EVM-compatible networks have also been conducted on Hyperledger Besu and Quorum (ConsenSys), typically reporting throughput in the range of 50–200 TPS for simple value-transfer transactions under IBFT/IBFT2 consensus (Fan et al., 2020, 2022). But the throughput for complex state-modifying smart-contract calls, like credential registration involving multiple SSTORE operations, is way lower. There’s also not a lot of published data for this workload type on live consortium networks.

A key technique used within these frameworks is stress testing, in which the system is pushed to its operational limits by increasing the transaction load (Huang et al., 2021). This process is essential for estimating maximum sustainable throughput and identifying primary performance bottlenecks, which may result from network propagation delays, validator computational capacity, or system constraints such as the block gas limit (Kleinfurber and Vengadasalam, 2024).

In addition to empirical testing, some researchers employ analytical modeling approaches (e.g., queuing theory) to predict performance. In this paradigm, the transaction memory pool (mempool) is modeled as a queue and validators are modeled as servers, enabling mathematical estimates of metrics such as transaction confirmation time under varying arrival rates (Menasce et al., 2004).

2.3.1 Gas Mechanics and Cost Optimization

The Ethereum Virtual Machine (EVM) is a sandboxed, quasi-Turing-complete environment that runs smart contract code and is compatible with the Bloxberg network (Zheng et al., 2017). This compatibility allows our study to draw directly on the principles of EVM operation, particularly its resource accounting mechanism known as gas.

Gas quantifies the computational effort required to execute blockchain operations. Each EVM opcode has a fixed gas cost, ranging

(Zheng et al., 2017) from a simple operation such as addition (3 gas) to storage writes (up to 22,100 gas) and cryptographic hashes (30+ gas). When submitting a transaction, a user specifies the gas price they are willing to pay for each unit of gas. The product of this gas price and the total gas consumed determines the transaction fee. This mechanism serves two purposes: it mitigates infinite loops and denial-of-service (DoS) attacks, and it compensates validators for the computational resources required to execute and verify transactions (Mougayar, 2016).

Within the EVM gas schedule, no operation is more significant for decentralized-application (dApp) design than writing to contract storage. Storage is the persistent key-value store that maintains a contract’s state across transactions. These operations are, by design, among the most expensive actions in the EVM. The SSTORE opcode, which writes a 32-byte word to storage, has a particularly punitive cost structure (Zheng et al., 2017):

- Initializing a storage slot (zero-to-non-zero write): 22,100 gas (which includes a 2,100-gas cold-access surcharge).
- Updating an existing non-zero storage slot: 5,000 gas.

These high costs reflect the work required to update the global state tree, which must be replicated across all nodes. The transaction batching pattern examined in this paper is primarily motivated by this economic disincentive for state changes, a fundamental aspect of EVM design.

Batching combines multiple logical operations into a single transaction to reduce fixed per-transaction overhead. On EVM-compatible networks, each transaction incurs a base cost of 21,000 gas, independent of the complexity of the invoked smart-contract function (Mougayar, 2016). This base cost covers transaction-processing work such as nonce checking and signature verification. For example, issuing 100 certificates via 100 separate transactions pays the 21,000-gas base cost 100 times. By contrast, issuing all 100 certificates within a single batched transaction pays this overhead once, effectively amortizing it across the 100 logical

operations (Mougayar, 2016). This established optimization technique is a key component of efficient smart-contract design (Kong et al., 2022). Alternative approaches to scalability include off-chain aggregation with Merkle tree commitments (where a single root hash anchors many credentials), layer-2 rollup strategies that

bundle execution off-chain and post compressed proofs on-chain, and event-based logging (using EVM LOG opcodes instead of SSTORE), which is cheaper but sacrifices on-chain queryability (Fan et al., 2020; Rondelet and Zajac, 2019).

3 SYSTEM ARCHITECTURE AND IMPLEMENTATION

To ensure efficiency and support GDPR compliance, we adopted a hybrid on-chain/off-chain architecture. The system follows the “Trust Triangle” model and comprises three primary roles: the issuer (university), the holder (student), and the verifier (employer). This architecture is broadly aligned with the W3C Verifiable Credentials data model and the Self-Sovereign Identity (SSI) paradigm, in which credential holders maintain control over their data while issuers and verifiers interact through decentralized trust registries (Preukschat and Reed, 2021).

3.1 Technology Stack

The application is built as a web platform. The frontend is developed in TypeScript using the Next.js framework. The backend API is implemented in TypeScript using Express and tRPC and handles the business logic. Off-chain storage is provided by a PostgreSQL database, which stores user accounts, certificate templates, and the full certificate payload (JSON-LD verifiable credentials) to ensure fast retrieval and data privacy. For the blockchain layer, we use the Bloxberg network. Smart contracts written in Solidity manage the registry of authorized issuer DIDs and the hashes of issued certificates. The DID method used for issuer and certificate identification on Bloxberg is inspired by the did:blox specification (Gono et al., 2025), which provides a secure and efficient decentralized identifier scheme tailored to scientific blockchain ecosystems.

3.2 Target Smart Contract

The CertificateRegistry smart contract, originally developed by Zák拉斯ník et al. (2024), serves as the baseline for our experiment. The primary purpose of the contract is to act as an immutable, on-chain registry that links credential issuers to the credentials they issue.

The baseline contract provides two state-modifying functions that serve as the subjects of our performance analysis. The issuance function, defined as `issueCertificate(bytes32 certificateDID, bytes32 issuerDID)`, takes the certificate identifier and the issuer identifier and records their linkage in the contract’s storage. The revocation function, defined as `revokeCertificate(bytes32 certificateDID)`, marks a previously issued credential as invalid. Both functions perform SSTORE operations that modify the contract’s persistent state. We include these technical signatures because they directly determine the gas cost profile analyzed in Section 5.3; each `bytes32` parameter contributes 32 bytes of calldata (512 gas) and each SSTORE invocation incurs the costs described in Section 2.3.

3.3 The Bloxberg Production Network Environment

All tests were conducted on the Bloxberg mainnet. The configured block time was 15 s; we validated this against our observations, measuring a mean observed block interval of 15.2 s ($\sigma = 1.8$ s, $n = 847$ blocks) during the experimental window, with occasional deviations attributable to validator availability fluctuations. The block gas limit, an important constraint

defining the maximum computational workload per block, was approximately 30,000,000 gas. All interactions with the network were

routed through the official public JSON-RPC endpoint: <https://core.bloxxberg.org> (Kleinfischer and Vengadasalam, 2024).

4 EXPERIMENTAL DESIGN AND METHODOLOGY

To evaluate the operational readiness of the application for real-world deployment, we conducted a series of controlled performance tests on the live Bloxxberg network. The goal was to assess the system’s responsiveness and throughput under representative workloads that mirror the typical operations of a university registrar’s office. We designed three testing scenarios corresponding to the principal operations in the certificate lifecycle, each representing a workload type for which quantitative data is missing in the current literature.

4.1 Testing Scenarios

We tested the following scenarios, each exercising a distinct smart-contract interaction pattern:

1. *Certificate issuance*

(*state-modifying write*):

We invoked the `/certificates` endpoint, which generates a verifiable credential, computes its SHA-256 hash, and submits a transaction calling `issueCertificate()` on the blockchain to register the hash. This is the most gas-intensive operation and the primary subject of our stress tests.

2. *Certificate revocation*

(*state-modifying write*):

We invoked the `/certificates/:id/revoke` endpoint to simulate an administrator invalidating a certificate (e.g., due to plagiarism or administrative error), which requires an on-chain state update via `revokeCertificate()`. This scenario tests a lighter write operation under identical load conditions.

3. *Credential verification*

(*read-only*):

We invoked the `/certificates/:id/valid` endpoint to measure how quickly a third party can verify a credential. This operation reads

from the blockchain state without submitting a transaction and therefore incurs no gas cost.

4.2 Experimental Schedule and Repetitions

For the issuance and revocation scenarios, we tested 10 discrete load levels: 1, 2, 5, 10, 15, 20, 25, 30, 40, and 50 concurrent requests. Each load level was repeated 10 times (10 independent experimental runs), yielding a total of 100 runs per scenario and approximately 1,550 individual transactions for the issuance scenario alone. The verification scenario was tested at the same 10 load levels with 10 repetitions each. Between successive runs at the same load level, we imposed a 120-second cooldown to allow the mempool to clear and avoid carryover effects.

4.3 Testing Environment and Tools

The test harness was developed using Node.js (v20 LTS) and is publicly available at <https://github.com/MENDELUI-PEF-UI-SMART/bloxxberg-benchmark> to support reproducibility. We used the Ethers.js library (v6.9) to interact with the Bloxxberg blockchain.

Workload Generator

A custom script capable of generating asynchronous HTTP requests to our API endpoints at controlled concurrency levels (load injection). We implemented detailed timestamp logging with millisecond precision at (i) request submission, (ii) API response receipt, and (iii) final blockchain confirmation via event subscription.

Metrics Monitored

For each transaction, we recorded the following:

- *Latency*: Total time from initiating an API call to the transaction’s confirmation in a

block, measured end-to-end from the client perspective.

- *Throughput*: Number of successful certificate registrations (or revocations) confirmed per second at each load level.
- *Gas consumption*: Gas used by contract interactions, decomposed into base transaction cost (21,000 gas), calldata cost, SSTORE cost, and remaining execution overhead.

4.4 Statistical Analysis and Outlier Handling

Testing on a live, shared consortium network such as Bloxberg introduces variables that can-

not be fully controlled, including foreign traffic from other applications and users. To ensure our metrics reflected the system's standard performance rather than network anomalies, we applied a trimmed mean approach by discarding the highest and lowest 5% of latency values within each load level. We report the mean, standard deviation (σ), and 95% confidence interval (CI) for each metric at each load level, computed across the 10 independent runs. Confidence intervals were calculated using the t -distribution with 9 degrees of freedom.

5 RESULTS AND ANALYSIS

This section presents the empirical results obtained from stress-testing the API endpoints across the three scenarios. All reported statistics are computed from 10 independent runs per load level after applying the 5% trimmed mean filter.

5.1 Latency Versus Offered Load

We first evaluated how the system responds as request intensity increased for the issuance scenario. We define three load regimes based on observed behavior: low load (1–5 concurrent requests), where all transactions fit within a single block; moderate load (10–20 concurrent requests), where transactions begin to span multiple blocks; and high load (25–50 concurrent requests), where the block gas limit is consistently saturated and queuing effects dominate.

As shown in Fig. 1, the baseline end-to-end latency for a single issuance request is 21.8 s (SD = 2.4 s, 95% CI [20.1, 23.5]). This value exceeds the configured 15 s block time because the measured latency encompasses the entire pipeline: API processing and credential generation (~ 1.2 s), transaction construction and signing (~ 0.3 s), submission to the RPC endpoint and propagation to the validator set

(~ 0.5 s), and waiting for the transaction to be included in the next block (up to one full block interval of ~ 15 s, depending on submission timing within the block cycle). The sum of these components yields the observed ~ 21.8 s mean. The system remains stable under low load (1–5 requests), with latency increasing only marginally to 24.1 s (SD = 2.8 s) at 5 concurrent requests. A clear inflection point occurs at approximately 10 concurrent requests (moderate load), where the block gas limit begins to prevent all transactions from entering the next immediate block. Beyond this point, pending transactions queue for subsequent blocks, and latency increases sharply: at 30 concurrent requests, mean latency reaches 68.3 s (SD = 8.7 s), and at 50 concurrent requests, it rises to 142.6 s (SD = 18.2 s).

5.2 Throughput Analysis

We measured effective throughput, defined as the rate at which issued certificates are successfully recorded on-chain, at each load level.

As shown in Fig. 2, the application reaches a maximum sustained throughput of 4.2 TPS (SD = 0.3, 95% CI [3.9, 4.5]). In the low-load regime (1–5 concurrent requests), throughput

scales roughly linearly with the offered load. Beyond the inflection point at 10 concurrent requests, throughput plateaus: increasing the number of concurrent requests does not result in faster processing; it only increases latency. This saturation point is determined by the per-block capacity, which is a function of the block gas limit (30,000,000 gas), the gas

cost of a single issueCertificate transaction ($\sim 142,000$ gas), and the 15 s block interval. The theoretical maximum per-block capacity is $30,000,000 / 142,000 \approx 211$ transactions per block. With a 15 s block interval, this yields a theoretical ceiling of approximately 14.1 TPS. The observed 4.2 TPS is well below this ceiling; the gap is attributable to several factors not

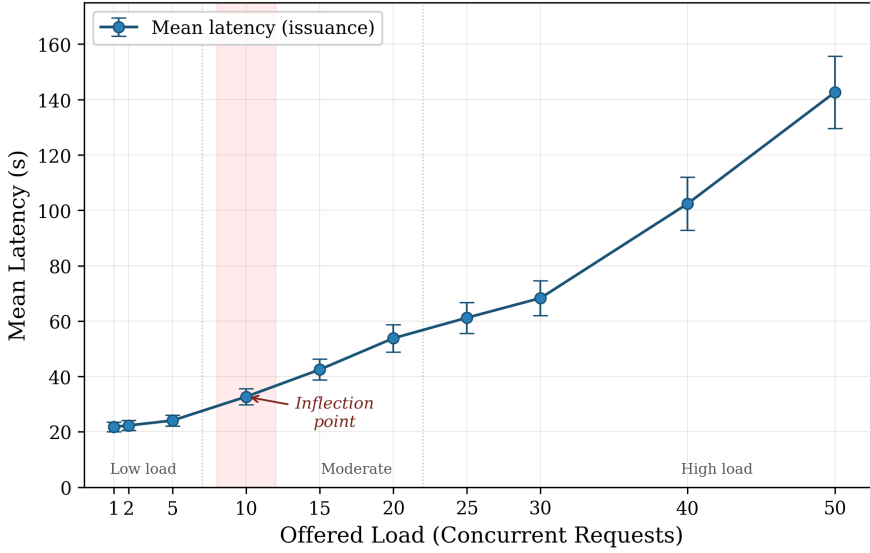


Fig. 1: Mean latency (s) versus offered load (concurrent requests) for the issuance scenario. Error bars represent 95% confidence intervals ($n = 10$ runs per load level). Baseline single-request latency is 21.8 s.

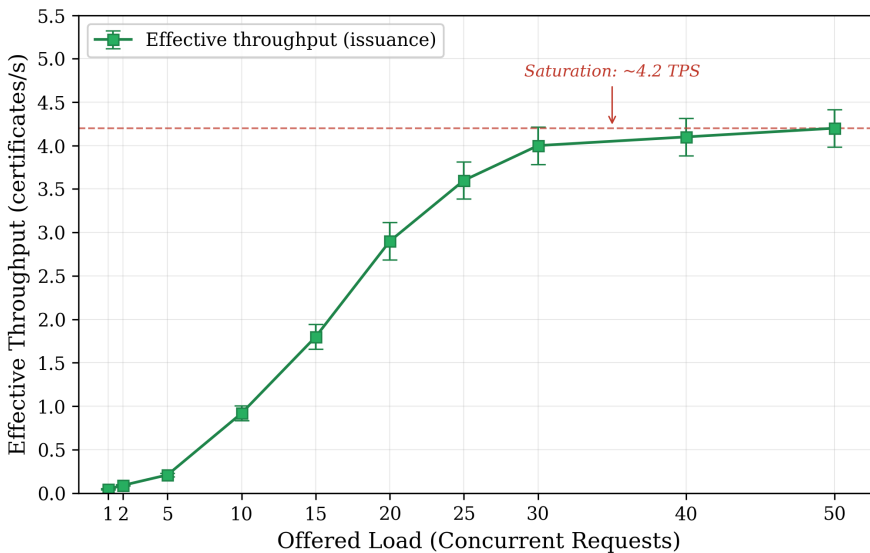


Fig. 2: Effective throughput as a function of offered load (concurrent requests). Error bars represent 95% confidence intervals ($n = 10$). Throughput saturates at approximately 4.2 TPS.

captured by the simple gas-limit calculation: (i) our test harness submits transactions sequentially from a single account, creating a nonce serialization bottleneck that prevents full block saturation; (ii) API-layer processing adds ~ 1.5 s per request before the transaction reaches the mempool; and (iii) RPC endpoint queuing under concurrent load introduces additional propagation delays. Thus, the 4.2 TPS figure reflects the end-to-end application throughput rather than the raw blockchain consensus limit.

5.3 Revocation and Verification Performance

To provide a complete lifecycle assessment, we benchmarked the revocation and verification operations under the same load conditions.

The revocation function (`revokeCertificate`) exhibited a mean gas consumption of 48,200 gas per operation ($SD = 320$), substantially lower than issuance because it modifies a single existing storage slot (a non-zero-to-non-zero SSTORE at 5,000 gas) rather than initializing new slots. Mean latency for a single revocation request was 19.4 s ($SD = 2.1$ s, 95% CI [17.9, 20.9]), slightly lower than issuance due to the reduced computational work. Under high load (50 concurrent requests), revocation latency reached 126.8 s ($SD = 15.4$ s), and throughput saturated at approximately 10.1 TPS ($SD =$

0.8), reflecting the lower per-transaction gas cost that allows more revocations per block.

Verification (read-only) exhibited dramatically different characteristics. Because verification queries the blockchain state without submitting a transaction, it is not constrained by block intervals or gas limits. Mean verification latency was 118 ms ($SD = 34$ ms, 95% CI [94, 142]) for a single request. Even under 50 concurrent verification requests, latency increased only modestly to 287 ms ($SD = 62$ ms), confirming that the read path scales well and provides a highly responsive user experience for third-party verifiers.

5.4 Gas Cost Analysis and Decomposition

We analyzed the system’s economic efficiency by decomposing gas consumption at the EVM opcode level for the `issueCertificate` function.

The mean gas consumption for issuing a single credential was 142,080 gas ($SD = 410$, $n = 1,550$ transactions across all issuance runs). As shown in Fig. 3, this value remains constant regardless of network load, confirming that per-issuance cost is deterministic under the current contract design. Because the `issueCertificate` function executes the same EVM opcodes for every invocation, gas consumption is invariant

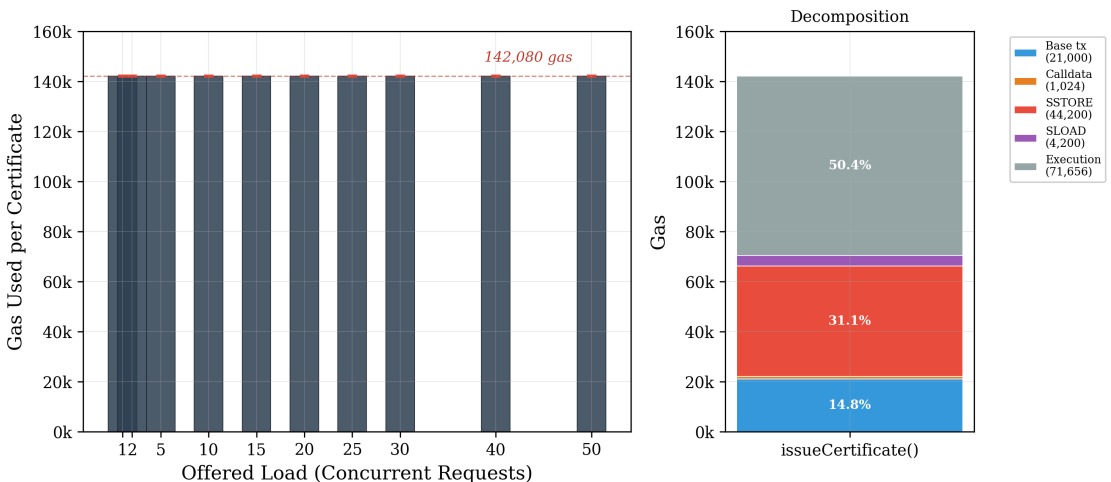


Fig. 3: Gas used per certificate issuance. Under single-issuance, gas consumption remains constant at approximately 142,080 gas per operation ($SD = 410$, $n = 1,550$ transactions). The stacked decomposition is shown in Tab. 1.

Tab. 1: Gas cost decomposition for a single `issueCertificate()` call (142,080 gas total)

Component	Gas	%	Description
Base transaction cost	21,000	14.8	Fixed per-tx overhead (nonce check, signature verification)
Calldata (2× bytes32, 64 B)	1,024	0.7	4-byte selector + 64 bytes params (16 gas/non-zero byte)
SSTORE (2× zero-to-nonzero)	44,200	31.1	Two slot initializations at 22,100 gas each
SLOAD (2× cold access)	4,200	3.0	Two cold reads at 2,100 gas each (auth + dup check)
Execution overhead	71,656	50.4	Function selector, memory, SHA3, LOG2 event
Total	142,080	100.0	SD = 410, $n = 1,550$ transactions

to external factors such as network congestion. Tab. 1 presents the opcode-level decomposition.

This decomposition reveals that SSTORE and the base transaction cost together account for 45.9% of total gas. In a batched design, the 21,000-gas base cost would be paid once per batch rather than once per certificate. For a batch of 100 certificates, this alone would reduce the per-certificate cost from 142,080 to approximately 121,290 gas, representing a 14.6% saving. Additional savings are possible if the batched contract optimizes storage layout (e.g., using packed structs or Merkle-root anchoring).

5.5 Economic and Monetary Cost Analysis

On the Bloxberg network, transaction fees are denominated in bergs (the native token), which have no monetary market value because bergs are distributed freely to consortium members. Consequently, the direct monetary cost of transactions on Bloxberg is effectively zero, which is a key advantage of using a permissioned academic blockchain for credential issuance.

However, to contextualize the results for institutions considering deployment on public or semi-public networks, we provide an equivalent cost analysis. If the same `issueCertificate` transaction (142,080 gas) were executed on Ethereum mainnet at a representative gas price of 20 Gwei and an ETH price of approximately 3,000 USD, the per-certificate cost would be approximately 0.0028 ETH or 8.53 USD. At this rate, issuing 5,000 certificates would cost approximately 42,650 USD, clearly prohibitive for most institutions. Batching 100 certificates per transaction would reduce the per-unit cost to approximately 7.28 USD, a 14.6% reduction. On layer-2 networks such as Arbitrum or Optimism, where gas costs are typically 10–50× lower, per-certificate costs could fall below 0.50 USD, making public-chain deployment more economically viable. These figures underscore the economic rationale for both (a) using a zero-fee permissioned network like Bloxberg for institutional use cases, and (b) implementing gas-efficient batching regardless of the deployment target.

6 DISCUSSION

The results in Section 5 are the first we know of that use statistics to measure how well a blockchain-based micro-credentialing system worked in the real world. In this section, we’ll talk about what this means for practitioners, compare our findings with what’s already out there, evaluate different scalability strategies, and acknowledge the limitations of our approach.

6.1 Contribution to Current Knowledge

This study fills three specific gaps in the literature. First, while benchmarking frameworks such as BlockBench (Dinh et al., 2017) and Hyperledger Caliper (Fan et al., 2020) have been applied extensively to testnets, our work provides production-network data for a real

credential workload, capturing the noise, variability, and pipeline effects that testnet studies cannot reproduce. Second, unlike prior studies that report only mean values, we present full distributional statistics (standard deviations and 95% confidence intervals), enabling readers to assess the reliability and reproducibility of the measurements. Third, the opcode-level gas decomposition and comparative economic analysis extend beyond the aggregate cost reporting found in existing dApp evaluations, providing actionable data for smart-contract optimization.

Compared to the permissioned EVM benchmarks reported by Fan et al. (2020) (50–200 TPS for simple transfers on Hyperledger Besu under IBFT2), our observed 4.2 TPS for complex state-modifying credential operations is substantially lower. This disparity is expected: each `issueCertificate` call consumes $\sim 142,000$ gas versus $\sim 21,000$ for a simple ETH transfer, reducing the number of transactions that fit within a single block by a factor of approximately $6.8\times$. The comparison highlights that raw TPS figures must be interpreted in the context of transaction complexity, supporting the recommendation of Cao et al. (2020) to adopt application-level throughput metrics.

6.2 Performance for Real Users

A key finding is that the application provides a highly responsive experience for its most frequent operation: verification. On average, third-party verifiers experience a delay of only 118 ms (SD = 34 ms). The observed 21.8 s mean latency is attributable to the blockchain confirmation pipeline (as explained in Section 5.1) and is managed effectively by the application’s asynchronous design, which separates the user interface from blockchain confirmation. The outlier filtering in our data processing confirms that 90% of issuance transactions complete within 26.5 seconds at low load, giving administrators a reliable expectation of system behavior.

When the throughput plateaus at 4.2 TPS (see Fig. 2), it means that for mass operations (like issuing 5,000 degrees at graduation), the

current one-by-one issuance strategy would take about 20 minutes of continuous processing. This is good enough for regular day-to-day operations, but it creates a bottleneck for high-volume seasonal events, which shows that we need a bulk issuance mechanism. Scalability strategies

To address the throughput bottleneck, we consider four complementary strategies, ranging from the most immediately actionable to more architecturally ambitious approaches.

Transaction batching. We propose implementing a `bulkIssueCertificates` smart-contract endpoint that accepts an array of certificate hashes. On the backend, a batching buffer aggregates pending certificates into optimal batch sizes (e.g., 50–100 certificates) and submits them as a single transaction. Based on our gas decomposition (Section 5.4), a batch of 100 certificates would reduce per-unit gas cost by approximately 14.6% through base-fee amortization. More importantly, it would reduce the number of transactions by $100\times$, effectively eliminating the per-block transaction limit as the bottleneck and increasing logical throughput to an estimated 93 certificates per block (approximately 6.2 per second).

Merkle tree aggregation. Instead of storing individual certificate hashes on-chain, a batch Merkle tree root could anchor an arbitrary number of credentials in a single `SSTORE` operation. This approach reduces on-chain storage costs to a constant (one 32-byte root per batch) regardless of batch size, at the cost of requiring off-chain Merkle proof generation for individual credential verification. The Blockcerts system (Blockcerts, 2016) employs a variant of this strategy.

Layer-2 rollup strategies. For deployments that require public-chain anchoring (e.g., for cross-institutional interoperability), optimistic or zero-knowledge rollups could batch credential state transitions off-chain and post compressed proofs on-chain, reducing per-credential costs by $10\text{--}50\times$. This approach is particularly relevant for Ethereum mainnet deployments, where our economic analysis (Section 5.5) demonstrates that L1 costs are prohibitive without optimization.

Event-based logging. Replacing SSTORE operations with EVM LOG opcodes (event emission) reduces the per-credential gas cost significantly, as LOG operations are substantially cheaper than persistent storage writes. However, this approach sacrifices on-chain queryability: events are stored in transaction receipts rather than in the contract’s state trie, meaning that verification requires a log-scanning approach rather than a direct state read. For use cases where verification frequency is low relative to issuance volume, this trade-off may be acceptable.

6.3 Threats to Validity

To ensure a balanced scientific interpretation of our results, we acknowledge several limitations and threats to validity.

External validity

The most significant threat to the generalizability of our performance data is the use of a single live network (Bloxberg). Results may not transfer directly to other PoA networks with different block times, gas limits, or validator configurations. Furthermore, our stress tests were capped at 50 concurrent users, which is sufficient for the target use case of a university registrar’s office but does not represent adversarial conditions or Internet-scale usage. At higher concurrency levels, additional bottlenecks may emerge in the API layer (Express/tRPC connection handling), the RPC endpoint (rate limiting at the Bloxberg gateway), or nonce management (concurrent transactions from the same account require sequential nonces, creating a serialization bottleneck). These architectural concerns warrant separate investigation beyond the scope of this paper.

Internal validity

Measurements were recorded from a client-side perspective using the Node.js test harness. This end-to-end measurement conflates blockchain processing time with standard internet latency

(RTT between our testing server and the Bloxberg RPC endpoint, measured at approximately 45 ms). While this is the most realistic representation of user experience, researchers interested in isolating pure blockchain processing time should subtract the RTT component.

Reliability

The live Bloxberg production network is subject to factors outside the experimenter’s control, including variable validator performance (hardware lag or temporary downtime) and foreign network traffic. We mitigated these effects through repeated measurements (10 runs per load level), off-peak scheduling, trimmed means, and reporting of standard deviations and confidence intervals. The raw data and analysis scripts are publicly available for independent verification.

6.4 Replicable Methodology

To support reproducibility and enable other researchers to adapt our approach for benchmarking different blockchain applications, we summarize the stress-testing methodology as a five-step protocol: (1) define testing scenarios corresponding to each state-modifying smart-contract function in the target application; (2) select load levels spanning from single-user baseline to the expected operational maximum, with a minimum of 8 discrete levels; (3) for each scenario and load level, execute a minimum of 10 independent runs with inter-run cooldown periods, logging timestamps at each pipeline stage; (4) apply trimmed-mean outlier filtering (5% tails) and compute descriptive statistics (mean, SD, 95% CI) per load level; (5) decompose gas consumption at the opcode level to identify optimization targets. The complete implementation of this protocol, including the workload generator, data collection scripts, and statistical analysis notebooks, is available at <https://github.com/MENDELUI-PEF-SMART/bloxberg-benchmark>.

7 CONCLUSION

This paper presented a performance analysis of a smart contract-based micro-credentialing system deployed on the production Bloxberg PoA blockchain. We developed a custom testing framework using Node.js and Ethers.js and evaluated the complete certificate lifecycle: issuance, revocation, and verification, under controlled load conditions with multiple repetitions per load level.

Our evaluation supports four main conclusions:

1. The application successfully handles the complete lifecycle of a certificate with predictable performance. Issuance latency averages 21.8 s (SD = 2.4 s) at baseline, verification responds in 118 ms, and the system operates stably under loads representative of a university registrar's office.
2. We identified a clear throughput saturation point at approximately 4.2 TPS for issuance and 10.1 TPS for revocation, governed by the interaction of per-transaction gas cost, block gas limit, and block interval.

3. The opcode-level gas decomposition reveals that base transaction overhead (14.8%) and SSTORE operations (31.1%) are the primary cost drivers, confirming that batching and alternative storage designs (Merkle roots, event-based logging) can yield significant per-certificate cost reductions.
4. By testing on the live network rather than in simulation and reporting full distributional statistics, we demonstrated that the PoA consensus provides consistent finality with quantifiable variance, and we established a replicable five-step methodology for future benchmarking studies.

Future work will focus on implementing and empirically evaluating the bulk-batching smart contract, conducting a comparative performance analysis against alternative platforms (Hyperledger Besu with IBFT2, Quorum), and extending the stress-testing methodology to include adversarial load patterns and nonce-management bottleneck analysis.

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Declaration of generative AI and AI-assisted technologies:

In preparing this article, we used OpenAI's ChatGPT tool (GPT-5 version). This tool was used for language editing, specifically to check the grammar and refine the wording of text already written in English. All output was checked by the author, who takes full responsibility for the accuracy and originality of the manuscript.

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MEASURING THE ECONOMIC EFFICIENCY OF THE EU ENERGY SECTOR

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ABSTRACT

This article evaluates the efficiency of primary energy production in EU countries using Data Envelopment Analysis. The analysis is based on aggregated macroeconomic and environmental data obtained from publicly available databases, with efficiency assessment explicitly accounting for carbon dioxide (CO₂) emissions as an undesirable output. The empirical results indicate relatively high average efficiency levels across the observed period, with several countries consistently operating on the efficiency frontier. In the second stage, a censored Tobit model is employed to examine the role of the energy mix. The findings suggest that both renewable and nuclear energy shares are positively associated with efficiency, with nuclear energy showing a somewhat stronger and more robust effect.

KEY WORDS

efficiency, energy mix, emissions, EU, primary energy production

JEL CODES

C61, C24, Q41, Q48, Q53

1 INTRODUCTION

The energy sector represents a fundamental pillar of the EU economy, playing a crucial role in ensuring economic stability, industrial competitiveness, and societal well-being. Although its direct contribution to GDP is not dominant, its importance lies primarily in its function as a core infrastructure enabling the operation of industry, transport, and services. As a key input

across virtually all sectors, energy availability and pricing significantly influence production costs, inflation dynamics, and overall economic performance. Consequently, the performance and efficiency of the energy sector are of central importance for sustainable economic development within EU Member States.

Beyond its economic role, the energy sector has gained increasing strategic and political importance. Recent geopolitical developments, particularly the Russia–Ukraine conflict, have exposed the EU’s dependence on external energy suppliers and heightened concerns regarding energy security, see, for example, Shoukat et al. (2024). As a result, strengthening supply resilience through diversification, infrastructure development, and deeper integration of the internal energy market has become a central policy priority. At the same time, the energy sector in the EU operates as a highly interconnected system, in which developments in one Member State can significantly affect others.

In parallel, the sector faces growing pressure to reduce greenhouse gas emissions and transition towards sustainable energy sources. Under the European Green Deal (European Commission, 2019), the EU aims to achieve climate neutrality by 2050, placing the energy sector at the core of decarbonization efforts. This transformation, however, entails substantial challenges, including high investment requirements, modernization of transmission networks, and the need to address the intermittency of renewable energy sources. These factors often create tensions between environmental objectives and economic efficiency.

As a result, the modern EU energy sector is undergoing a complex transformation characterized by the need to balance three fundamental dimensions: security of supply, affordability, and environmental sustainability (Kaschny, 2025). This so-called “energy trilemma” provides a key framework for evaluating both policy measures and sectoral performance. Given the increasing complexity and interdependence of energy systems, there is a growing need for analytical approaches focused on measuring efficiency and identifying its key determinants. Moreover, differences in market structures, regulatory environments, and energy mixes across Member States may lead to significant variations in efficiency levels, further underscoring the importance of systematic efficiency assessment.

1.1 Theoretical Background

Research on energy sector efficiency has expanded rapidly in recent years, particularly in response to the increasing importance of sustainability, decarbonisation, and energy security. A substantial body of literature focuses on evaluating efficiency at both the macro (country and regional) and micro (firm and sectoral) levels, with a strong emphasis on advanced quantitative methods such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

For instance, Kyshakevych et al. (2024) apply DEA models to evaluate the energy efficiency of 38 European economies over the period 2010–2018, demonstrating that substantial differences exist across countries and that less efficient nations can improve performance by adopting best practices from benchmark economies. In particular, the authors emphasize that effective strategies include a transition towards renewable energy sources and a reduction in dependence on fossil fuels, which are associated with improvements in overall energy performance.

The same period was analysed by Simeonovski et al. (2021), with the difference that their study focused exclusively on EU countries. The authors combined the efficiency analysis with an assessment of labour productivity and trends in energy intensity. Their results indicate significant differences between the performance of new and old Member States. Overall, they conclude that efficiency in the sector is relatively low (around 16%), while new Member States achieve, on average, approximately seven times higher efficiency compared to the old Member States. The unfavourable situation is further underlined by the finding that energy efficiency management did not improve over the analysed period. As a possible pathway for improvement, Simeonovski et al. (2021) suggest measures such as market liberalisation and the implementation of policies aimed at increasing overall economic productivity.

Significant differences among EU countries were also identified by Varvařovská and Staňková (2021), who did not measure efficiency directly using DEA or SFA models, but in-

stead estimated production functions for EU countries based on firm-level microdata. Their findings demonstrate how the structure of firms (and, consequently, the composition of different energy sources) influences the productivity of individual countries. The results indicate that, from a productivity perspective, firms (and thus countries) with a high share of renewable energy sources tend to exhibit lower overall productivity levels.

Many studies can be found that do not directly address the economic aspect of efficiency in the energy sector, but instead focus on other dimensions such as environmental issues, technological development, or sustainability. In recent years, examples of such studies include García-Álvarez et al. (2025), Gouveia et al. (2023), Kermeli et al. (2022) and Fidanowski et al. (2021).

Given the complexity of the analysed problem, researchers often adopt comprehensive approaches that require multi-stage analysis. For example, Basilio (2025) first applied a DEA model to estimate the efficiency of 27 EU countries over the period 2015–2022 and subsequently used fractional regression models to identify the factors influencing the obtained efficiency scores. Among the potential regressors, they considered variables such as energy prices, the business cycle, and the share of renewable energy sources.

Sun et al. (2024) employ a DEA model to obtain slack values (i.e. output surpluses and input shortages), which are subsequently decomposed using econometric approaches into three components: environmental, stochastic, and managerial factors. Based on panel data for 15 cities in Southwest China over the period 2010–2018, the authors are able to identify significant differences across individual cities.

Wu et al. (2026), using data for 14 Chinese prefectures and cities over the period 2016–2022, apply a combination of a DEA model to estimate efficiency and a Tobit model to identify the key factors influencing efficiency from a macroeconomic perspective. Among the determinants, tourism is identified as a factor negatively affecting efficiency, whereas human capital exerts a positive influence and

should therefore be further developed in future provincial strategies.

Jiang and Xie (2024) employ a dynamic spatial network DEA model to evaluate the environmental efficiency of China's power systems, with a particular emphasis on spatial interactions, captured through Moran's I test. Beyond highlighting spatial dependence, their results identify CO₂ emissions as the most significant factor contributing to inefficiency.

Zhang et al. (2020), in their evaluation of energy sector efficiency, also consider a variable capturing CO₂ emissions. However, unlike Jiang and Xie (2024), they incorporate it directly into the DEA model as an undesirable output, alongside GDP as a desirable output. A similar approach is adopted by Zhong et al. (2021), with the difference that they use value added as the desirable output and SO₂ and soot emissions as undesirable outputs.

1.2 Aim, Motivation and Contribution

This article focuses on analysing the efficiency of the energy sector across EU countries at an aggregated level, where each country represents a decision-making unit. The analysis is designed to capture cross-country differences in energy performance and is structured as a two-stage procedure, allowing both the measurement of efficiency and the identification of its potential determinants.

In the first stage, efficiency scores for individual EU countries are derived using aggregated macroeconomic data obtained from the EU KLEMS database. Economic efficiency is evaluated using the DEA method. To account for environmental aspects of energy production and consumption, CO₂ emissions are explicitly incorporated into the model as an undesirable output. This specification follows the methodological framework proposed by Jiang and Xie (2024), where undesirable outputs or inputs are directly embedded in the DEA model structure rather than being treated in a second-stage analysis. Such an approach allows for a more realistic representation of production

processes, especially in sectors with significant environmental externalities.

At the same time, the analysis takes into account differences in the structure of energy sources across countries. In line with Varvařovská and Staňková (2021), particular attention is devoted to the heterogeneity of the energy mix, as countries differ substantially in their reliance on fossil fuels, renewable energy sources, and nuclear power. These structural differences are expected to play an important role in shaping overall efficiency outcomes.

In the second stage, the determinants of efficiency are examined using a Tobit regression model, following Wu et al. (2026). The dependent variable in this stage is the efficiency score obtained in the first stage, while the explanatory variables capture the composition of the energy mix, represented by the shares of different energy sources. The Tobit model makes it possible to analyse how variations in the energy structure influence efficiency while accounting for the censored nature of the dependent variable.

2 DATA AND METHODS

Given that different data and methodological approaches are used in each stage, this section is divided into two parts corresponding to the two stages of the research.

2.1 DEA Model and Data for Efficiency Analysis

As already mentioned, economic data from the EU KLEMS database are used for the purposes of efficiency analysis. The most recent update (release 2025) provides aggregated annual data for individual EU countries up to 2021 (Luiss, 2026). In order to capture potential trends while avoiding substantial changes associated with technological progress, the period from 2018 to 2021 is selected for the analysis.

Similarly to Varvařovská and Staňková (2021), the model incorporates both labour and capital inputs. Specifically, labour is represented by the variable Total hours worked by persons engaged (in thousands of hours), while capital is captured by Gross fixed capital formation in current prices (in millions of national currency). As an output variable, Value added measured in current prices (in millions of national currency) is used. In addition, CO₂ emissions (in tonnes) are included in the DEA model as an undesirable output. This variable is obtained from the Eurostat database (Eurostat, 2026a).

Both databases allow for the selection of variables according to NACE classification;

therefore, only values corresponding to sector D (Electricity, gas, steam and air conditioning supply) are included in the analysis. Unfortunately, Cyprus and Malta had to be excluded from the analysis, as data on the capital factor in sector D are not available in the EU KLEMS database for these countries. As a result, the analysis covers the remaining 25 EU countries.

When working with economic data in an international comparative context, an additional issue arises from the fact that databases such as EU KLEMS provide data in national currencies, while not all countries use the euro. For this reason, the values for Bulgaria, Czechia, Denmark, Hungary, Poland, Romania, and Sweden are converted into euros using the average annual exchange rates provided by the European Central Bank (2026).

Descriptive statistics of the variables used in the DEA model by year are reported in Tab. 1.

To incorporate the emissions variable into the model as an undesirable output, the approach proposed by Seiford and Zhu (2002) was adopted, whereby undesirable outputs are incorporated using the translation approach. Let b_k denote the undesirable output. It is transformed as follows:

$$b_k^* = M_k - b_k, \quad (1)$$

where $M_k = \max_j(b_{jk}) + 1$ for each undesirable output k . The DEA model is then formulated as an input-oriented model (similarly to Kyshakevych et al., 2024, and Simeonovski et

Tab. 1: Descriptive statistics of variables used in the DEA model by year

Characteristics		2018	2019	2020	2021
Total hours worked	Min	2,428	2,553	2,609	2,756
	Average	74,252	75,412	76,618	79,617
	Median	41,806	42,288	41,848	44,063
	Max	391,105	394,453	401,120	410,892
Capital formation	Min	254	239	205	329
	Average	3,890	4,149	4,113	4,603
	Median	1,513	1,363	1,652	1,637
	Max	18,122	18,682	18,459	22,418
Value added	Min	408	445	452	478
	Average	7,495	8,185	8,308	8,806
	Median	4,660	4,936	4,780	5,090
	Max	33,611	38,525	37,901	40,357
Emission	Min	258,700	256,700	245,400	246,100
	Average	35,013,967	30,199,848	25,625,421	28,202,177
	Median	14,775,608	10,578,683	10,382,946	9,671,914
	Max	265,117,663	215,553,796	180,339,336	207,468,174

al., 2021), the model is specified under the assumption of variable returns to scale):

$$\begin{aligned}
 & \min \theta, \\
 \text{subject to } & \sum_j \lambda_j x_{ij} \leq \theta x_{io}, \\
 & \sum_j \lambda_j y_{rj} \geq y_{ro}, \\
 & \sum_j \lambda_j b_{kj} \geq b_{ko}, \\
 & \sum_j \lambda_j = 1, \\
 & \lambda_j \geq 0
 \end{aligned} \tag{2}$$

DEA models are calculated separately for each year, as the analysed period includes, among other things, the COVID-19 pandemic, during which significant shifts in the production possibility frontier can be expected, as has been demonstrated in other economic sectors (see, for example, Staňková et al., 2025).

2.2 Tobit Model and Determinants of Efficiency

In the second stage of the analysis, the factors influencing the efficiency of individual countries are examined based on data on energy

production in EU countries. Using data from the Eurostat database (Eurostat, 2026b), three variables are included in the model: fossil fuels (comprising solid fossil fuels, natural gas, and oil and petroleum products excluding the bio-fuel component), renewables (renewables and biofuels), and nuclear energy. All variables are expressed in thousand tonnes of oil equivalent.

As all data in the first stage of the analysis refer exclusively to domestic energy production, only primary production values are also used in the second stage. Descriptive statistics of primary energy production (in thousand tonnes of oil equivalent) for different types of energy sources are presented in Tab. 2.

Given that efficiency scores are bounded within the interval from 0 to 1, with the value of 1 typically occurring for more than one decision-making unit, the use of a standard linear regression approach is not appropriate. In particular, such models do not account for the censored nature of the dependent variable and may lead to biased and inconsistent estimates.

For this reason, a Tobit regression model is adopted in the second stage of the analysis. The Tobit model is specifically designed for situations in which the dependent variable is limited within a certain range, allowing for consistent

Tab. 2: Descriptive statistics of variables used in the Tobit model by year

Characteristics		2018	2019	2020	2021
Fossil fuels	Min	<1	<1	<1	<1
	Average	7,998	6,997	5,846	5,962
	Median	1,558	1,430	1,203	1,137
	Max	51,512	48,788	44,363	46,294
Renewables	Min	172	197	262	272
	Average	8,828	9,081	9,335	9,793
	Median	3,973	4,183	4,328	4,576
	Max	43464	45,689	46,594	47,204
Nuclear energy	Min	<1	<1	<1	<1
	Average	7,810	7,847	7,007	7,467
	Median	812	910	956	890
	Max	107,629	103,987	92,211	98,864

estimation in the presence of censoring (Greene, 2003; Tobin, 1958). In this study, it enables the examination of how differences in the structure of the energy mix influence the efficiency scores while properly accounting for their bounded nature.

Although DEA models are typically estimated separately for each period to account for potential changes in the production possibility frontier over time, the Tobit model is estimated in a pooled form in order to increase the number of degrees of freedom and improve the robustness of the results:

$$\begin{aligned}
 y_i^* &= x_i' \beta + \epsilon_i, \\
 \epsilon_i &\sim N(0, \sigma^2), \\
 y_i &= \max(0, \min(y_i^*, 1)),
 \end{aligned} \tag{3}$$

where i denotes the individual country, t denotes the time, y^* is the latent (unobserved) efficiency score, y is the observed efficiency score bounded between 0 and 1, β are unknown parameters to be estimated, ϵ is a random error term. As the Tobit model belongs to the class of regression models, it is necessary to examine potential violations of standard assumptions, particularly heteroskedasticity, autocorrelation, and non-normality of the error term (Greene, 2018). Such issues may affect the reliability of statistical inference and the validity of the estimated results. In the presence of these problems, bootstrap-based estimation can be employed to enhance the robustness of the inference, as it does not rely on strict distributional assumptions and provides empirically derived standard errors and confidence intervals (Cameron and Trivedi, 2005).

3 RESULTS

According to the results of the DEA model, the energy sector performs relatively well in the production of primary energy in the EU. The average efficiency during the observed period ranges between 78% and 83% (see Tab. 3). Median values are even higher, ranging from 78% to 93%. In addition to these aggregated indicators, Tab. 3 also presents efficiency scores for individual countries, including the average

score for the entire period 2018–2020, as well as the average ranking derived from these averages.

There are five countries (France, Germany, Luxembourg, Spain, and Sweden) that remain efficient throughout the entire observed period. These countries can therefore be considered the best performers in the production of primary energy in terms of labour and capital inputs.

Tab. 3: Estimated efficiency scores by country for each year

Unit	2018	2019	2020	2021	Average	Average rank
Austria	0.7627	0.7749	1	0.7910	0.8321	11
Belgium	0.5508	0.6396	0.8404	1	0.7577	17
Bulgaria	1	0.9975	0.9066	1	0.9760	7
Croatia	0.5667	0.6128	0.3532	0.7713	0.5760	23
Czechia	0.8472	0.7196	0.9642	0.7788	0.8274	12
Denmark	0.5546	0.6159	0.5515	0.6895	0.6029	22
Estonia	0.7251	0.7584	0.6227	0.9186	0.7562	18
Finland	0.6134	0.7991	0.7847	0.7449	0.7355	19
France	1	1	1	1	1	1
Germany	1	1	1	1	1	1
Greece	1	1	0.9950	1	0.9988	6
Hungary	0.4423	0.4057	0.6042	0.4599	0.4781	25
Ireland	0.5920	0.6674	0.8062	0.8722	0.7345	20
Italy	0.8057	0.8527	0.9287	0.7159	0.8258	13
Latvia	0.9539	1	0.3675	0.8447	0.7915	14
Lithuania	0.6954	0.5415	0.6751	0.6894	0.6504	21
Luxembourg	1	1	1	1	1	1
Netherlands	0.4929	0.6035	0.6063	0.5214	0.5560	24
Poland	0.8836	0.7898	1	1	0.9183	9
Portugal	1	1	1	0.7906	0.9476	8
Romania	0.5226	1	1	1	0.8807	10
Slovakia	0.6467	0.7224	0.9529	0.7377	0.7649	15
Slovenia	0.7799	0.7823	0.7852	0.7042	0.7629	16
Spain	1	1	1	1	1	1
Sweden	1	1	1	1	1	1
Average	0.7774	0.8113	0.8298	0.8412		
Median	0.7799	0.7898	0.9287	0.8447		

According to Tab. 3, Hungary ranks in the worst position, with an average efficiency of 48%, i.e. several tens of percentage points below both the sectoral average and median. It is the only country that does not reach at least 50% efficiency on average over the entire period. Alongside Hungary, other highly inefficient countries include Croatia, Denmark, and the Netherlands.

An alternative way of constructing the ranking is presented in Tab. 4, where the focus is not on the absolute value of efficiency scores; instead, countries are ranked for each year according to their position. These rankings are then averaged, and the final ranking of countries is determined based on this average position.

This methodological change in constructing the ranking does not alter the positions of the five best-performing countries (i.e. the efficient countries), nor does it affect the position of the least efficient country, Hungary, followed by the Netherlands. For the remaining countries, only minor changes in rankings can be observed, amounting to at most two positions, which can be considered negligible.

A more detailed examination of both Tab. 3 and Tab. 4 shows that the rankings (as well as the absolute efficiency values) changed in 2020, when the COVID-19 pandemic began in Europe. This challenging period was addressed differently by individual countries through various restrictive measures. The effects on

Tab. 4: Evaluation of countries based on their rankings in individual years

Unit	2018	2019	2020	2021	Average rank	Final rank
Austria	14	15	1	14	11.00	11
Belgium	22	20	15	1	14.50	15
Bulgaria	1	10	14	1	6.50	9
Croatia	20	22	25	17	21.00	22
Czechia	11	18	11	16	14.00	13
Denmark	21	21	23	22	21.75	23
Estonia	15	16	20	11	15.50	16
Finland	18	12	18	18	16.50	19
France	1	1	1	1	1	1
Germany	1	1	1	1	1	1
Greece	1	1	10	1	3.25	6
Hungary	25	25	22	25	24.25	25
Ireland	19	19	16	12	16.50	19
Italy	12	11	13	20	14.00	13
Latvia	9	1	24	13	11.75	12
Lithuania	16	24	19	23	20.50	21
Luxembourg	1	1	1	1	1	1
Netherlands	24	23	21	24	23.00	24
Poland	10	13	1	1	6.25	8
Portugal	1	1	1	15	4.50	7
Romania	23	1	1	1	6.50	9
Slovakia	17	17	12	19	16.25	17
Slovenia	13	14	17	21	16.25	17
Spain	1	1	1	1	1	1
Sweden	1	1	1	1	1	1

Sector D can be observed in these changes in efficiency during this period, which are strongly influenced not only by shifts in the production possibility frontier, but also by changes in its shape, against which individual country efficiency is assessed. Examples of substantial individual changes resulting from these alterations in both the position and shape of the production possibility frontier can be seen, for instance, in Croatia and Latvia.

The second part of the analysis focuses on identifying variables that may influence the obtained efficiency scores. To mitigate the problem of heteroskedasticity, which is likely driven by substantial data heterogeneity, the variables were transformed from their original units (thousand tonnes of oil equivalent) into shares. Tab. 5 presents the key information

for the final Tobit model, including variables representing the shares of different types of energy.

During the model specification process, it was found that the time factor is not statistically significant, indicating that no clear trend was identified over the observed period. The final model therefore retains the variables representing the shares of renewable and nuclear energy, both of which are statistically significant at the 10% significance level. The intercept term is positive and highly significant, reflecting a relatively high baseline level of latent efficiency across the sample.

The parameters associated with both renewable and nuclear energy indicate a positive effect. However, the estimated coefficients reported in Tab. 5 relate to the latent efficiency

Tab. 5: Tobit Model Estimates

Coefficients	Estimates	Std. Error	Z-value	P-value
Intercept	0.71634	0.06095	11.75289	<0.00001
Renewables	0.14129	0.08253	1.71190	0.08691
Nuclear energy	0.18224	0.09781	1.86323	0.06243
Ln(Scale)	−1.60140	0.07785	−20.57062	<0.00001

variable rather than directly to the observed efficiency scores. The uncensored effects can be approximated using the scale parameter. The value of the scale parameter (after exponentiation) is 0.2016. This relatively low value, combined with the high intercept, implies that the value of the standard normal cumulative distribution function is very close to one. As a result, the marginal effects on observed efficiency are very similar to the original Tobit model coefficients.

Specifically, a 10 percentage point increase in the share of renewable energy is associated with an increase in efficiency of approximately 0.014, while a comparable increase in the share of nuclear energy corresponds to an increase of about 0.018. This suggests that the effect of nuclear energy is somewhat stronger.

To enhance the robustness of the results, bootstrap-based standard errors were computed (1000 repetitions). The bootstrap results suggest that the estimated coefficients are stable, as indicated by the negligible bias across all

parameters (see Tab. 6). Bootstrap-based inference was further used to assess the statistical significance of the estimated coefficients. The resulting p -values largely confirm the original findings, with renewable energy remaining weakly significant at the 10% level (p -value = 0.091). In contrast, the effect of nuclear energy becomes statistically significant at the 5% level (p -value = 0.049) when evaluated using bootstrap standard errors, suggesting a somewhat stronger and more robust relationship.

Tab. 6: Bootstrap Statistics

Coefficients	Original	Bias	Std. Error
Intercept	0.71634	0.00014	0.06310
Renewables	0.14129	−0.00055	0.08364
Nuclear energy	0.18224	−0.00283	0.09239

Overall, the results suggest that the energy mix plays a role in shaping efficiency outcomes, with nuclear energy showing a more robust association, while the effect of renewable energy remains less conclusive.

4 DISCUSSION, LIMITATIONS AND FUTURE DIRECTIONS

Based on the DEA model, a total of five countries were identified as being 100% efficient throughout the entire observed period, namely France, Germany, Luxembourg, Spain, and Sweden. These countries clearly share the characteristic of being highly economically developed, which is also associated with a high level of technological advancement (European Commission, 2025). From the perspective of energy production, they have in common a relatively limited domestic fossil fuel base, and they can also be described as countries representing

low-carbon energy models (Wojciechowski et al., 2023).

A closer look at the strategies of, for example, France and Germany reveals that it is possible to achieve an efficient state even through fundamentally different approaches. France is undoubtedly a country with a large share of energy generated from nuclear power. In contrast, Germany is well known for its opposition to nuclear energy. Although the complete phase-out was finalized in 2023, a significant reduction in the share of nuclear energy had already taken

place during the observed period. Specifically, in 2021, Germany shut down three of its six remaining nuclear power plants (Euronews, 2021). Germany's strategy, which also resulted in efficiency within the DEA model, is based on a strong deployment of renewable energy sources.

The suitability of both strategies is further supported by the results of the Tobit model, which indicate a positive effect on efficiency for countries with a high share of both nuclear energy and renewable energy sources. From this perspective, it is therefore not necessary to direct all countries toward a single common European strategy, as an efficient state can be achieved through fundamentally different approaches.

The mere dominance of either nuclear energy or renewable energy in a given country does not automatically represent a key to success, as demonstrated by the results for Hungary. According to the cluster analysis presented in Varvařovská and Staňková (2021), Hungary belongs to the same cluster as France in terms of its energy mix, due to the strong share of nuclear energy. Nevertheless, these countries are positioned at completely opposite ends of the ranking. Although the DEA model itself does not include any variable explicitly capturing the transformation process, it does reflect production efficiency, which is logically also determined by technological progress. France operates a highly developed system consisting of numerous reactors across nearly two dozen nuclear power plants, allowing it to cover more than half of its energy production from nuclear sources (Euronews, 2020). In contrast,

Hungary relies on a single nuclear power plant, Paks, which, although also capable of producing roughly half of the country's required energy, is based on Russian technology (see, for example, Sarlós, 2015). Although both France and Hungary rely heavily on nuclear energy, differences in technology mean that France ranks among the five efficient countries, whereas Hungary is positioned at the bottom of the ranking.

As already mentioned, this study focuses exclusively on the production of primary energy; therefore, all variables (labour, capital, and emissions) are related solely to the activities of sector D, which can be considered a limitation of this research. Countries (not only within the EU) actively trade energy, yet these linkages are not incorporated into the constructed DEA model. Future research could extend the model by including these energy flows, either in the form of a net export variable or by directly accounting for the volumes of exports and imports.

Another limitation of this study lies in the borderline p -values obtained in the Tobit model. Future research could address this issue by adopting a less aggregated approach and including variables such as biofuels, wind energy, solar energy, and geothermal energy separately. However, such a model would require a panel dataset with a longer time horizon in order to ensure a sufficient number of degrees of freedom. For longer time periods than the four years considered in this study, it would also be necessary to more thoroughly analyse shifts in the production possibility frontier resulting from technological progress, which can be expected in longitudinal research.

5 CONCLUSIONS

This study examined the efficiency of primary energy production in 2018–2021 across selected EU countries using the DEA and Tobit models, with a particular focus on the role of different energy sources. Efficiency is derived from aggregated economic indicators with respect to the amount of CO₂ emissions produced, which are treated as an undesirable output in the DEA

model. Based on the model results, France, Germany, Luxembourg, Spain, and Sweden can be identified as the leading countries. Although these countries do not follow identical strategies in terms of their energy mixes, all of them remained efficient throughout the entire observed period. As evidenced by the results of the Tobit model, high shares of both

renewable and nuclear energy have a positive effect on the efficiency of individual countries. Taken together, these findings suggest that a

uniform European energy strategy may not be necessary, as countries can achieve efficiency through diverse approaches.

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EVALUATING THE FINANCIAL IMPLICATIONS OF BUSINESS PROCESS OUTSOURCING: A CASE STUDY OF MIZA INTERNATIONAL CO. IN SAUDI ARABIA

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ABSTRACT

This study examines the financial implications of business process outsourcing (BPO) in the context of Saudi Arabia's Vision 2030 economic diversification agenda, using Miza International Co. as a case study. Drawing on Transaction Cost Economics and the Knowledge-Based View, the research analyzes how BPO selection quality and cost-management practices influence firm-level financial performance. Data were collected from 384 stakeholders and analyzed using multiple linear regression. The results indicate that both effective BPO selection ($\beta = 0.234$, $p < 0.001$) and cost management ($\beta = 0.168$, $p < 0.001$) significantly enhance financial performance, jointly explaining 47.5% of the variance. Strategic alignment emerged as the strongest predictor, suggesting that BPO functions primarily as a strategic value-creation mechanism rather than solely a cost-reduction tool in this emerging market context. The findings provide practical and policy-relevant insights for firms leveraging outsourcing to support national diversification objectives.

KEY WORDS

business process outsourcing, financial performance, Vision 2030, emerging markets

JEL CODES

D23, L24, M11, M15, M16, O32

1 INTRODUCTION

Business Process Outsourcing (BPO) has experienced a tremendous transformation in the last three decades. What started out as a strategic cost-cutting exercise has evolved into an effective strategic tool. Such a change enables current businesses to become highly efficient

in their operations, quickly gain expertise in a specialized field, and strictly concentrate on their areas of competence. In a mature, developed economy, BPO is inherently associated with more general approaches towards organizational change and is broadly considered

as a means of ensuring a competitive edge in a highly dynamic and turbulent environment. Companies in various sectors take advantage of outsourcing to optimize resources, guarantee the flexibility of response to market turbulence and how economies of scale could not have been reached without external activities.

There is a fast geographical shift in the global outsourcing arena. Although the leaders in the industry such as India and the Philippines still hold dominance in the industry, the new economies are actively competing in the industry. More importantly, much of these new market entries are not only pushed by corporate action but also national policies that have considered outsourcing as an important tool of economic modernization and globalization. The gulf region, especially Saudi Arabia, is a very interesting topic of this study, with the massive levels of economic and social changes that are underway. The main object of this change is the agenda of the Vision 2030 that is the ambitious plan to radically diversify the national economy beyond oil dependence, increase the pace of the development of the strong private sector, and improve the overall productivity.

In this regard, BPO implementation in Saudi Arabia is not just a company strategy, but a national development tool. It allows local companies to increase their efficiency in operations, reduce the need to be dependent on government subsidies and acquire within a short period of time the ability to compete based on the international standards. Outsourcing is also being viewed as one of the core processes in ensuring the ambitious productivity gains as envisaged in Vision 2030. Nonetheless, in spite of such a solid national policy recommendation and increased corporate usage, there is quite a thin academic literature concerning financial performance and operating efficacy of BPO in Saudi Arabia. Such under-academic focus limits contributions of both the managers and the policymakers who need evidence based conclusions in order to manoeuvre the outsourcing in this particular emerging-market environment successfully.

The sparse evidence in the Gulf region is in comparison to the widespread empirical research done on the developed markets posing

both conceptual and practical challenges. In principle, it makes it difficult to develop subtle insights that take into consideration the institutional, cultural, and regulatory peculiarities of emerging markets. In practice, it compels regional managers to often use context-based lessons in order to adapt to their unique environment of operation, increasing the risk of misalignment and poor performance. This is especially sharp in locations such as Saudi Arabia where enterprises may be faced by steep learning curves and where the localized ecosystem of BPO vendors, regulators and intermediaries is yet to be established.

The current study focuses on Miza International Co. that can be used as a good example of these dynamics. The presence of the company in the multitude of out-sourcing programs is very strategic and in line with the national Vision. Nonetheless, there are internal reports that show inefficiencies in its operations always, which is contrary to the investments. It is this fundamental paradox that makes it necessary to analyze the exact mechanisms that condition the success of outsourcing. The paper goes beyond the broad question of is outsourcing necessarily good and instead focuses on the key aspects of organization practices, in terms of the quality of BPO decision-making and the rigor of cost management practices, that generate differentiated financial performance results.

The analysis of these practices in the given study is based on a dual theoretical model based on the Knowledge-Based View (KBV) and Transaction Cost Economics (TCE). TCE focuses on reducing the coordination and contractual expenses of outsourcing, which is concentrated on risks, such as opportunism and incomplete contracts. Conversely, KBV accentuates the strategic potential of BPO to tap external knowledge and professional skills thus strengthening the competitive edge of a firm. Using this integrated framework to the Saudi case, this study will do not only provide the much-needed empirical evidence to the current literature on BPO in emerging markets but will also widen theoretical discussions on the necessity of the interaction between local institutional factors and organizational decision-making on the success of outsourcing.

2 LITERATURE REVIEW

Business Process Outsourcing (BPO) has been a well-known competitive advantage, as well as a strategic option among companies trying to attain efficiency, scale, and flexibility. Early conceptualizations have advocated the role of BPO in assisting organizations to minimize the cost of operations and re-allocate resources to the core business functions (Willcocks et al., 2004). However, with time, there has been a growing perception of outsourcing as a multidimensional concept where monetary factors are not the sole determinants but institutional, contractual, and knowledge-based forces may also play a crucial role. The literature is dominated by two theoretical perspectives, namely, Transaction Cost Economics (TCE) and the Knowledge-Based View (KBV). Both give their own contribution towards the reason as to why firms outsource, and the circumstances under which outsourcing improves or deteriorates performance.

The concept of TCE developed by Williamson (1998) suggests that companies will outsource when external suppliers are able to execute tasks at a reduced joint production and transaction costs, in contrast to internal structures of governance. The reasoning is that by outsourcing, the firms will be able to bypass the fixed cost of vertical integration. Yet, as numerous research papers have demonstrated, the expected savings can be undone by transaction costs, including contract negotiation, contract monitoring, contract enforcement, and contract supplier switching (Lacity et al., 2011; Liu and Tyagi, 2016). Outsourcing success is not entirely a chance scenario; thus, it needs to be governed, relational contracting, and risk management (Handley, 2012; Neves et al., 2014).

In comparison, KBV views outsourcing in the form of a boundary decision that is influenced by knowledge and abilities (Grant, 1996). The outsourcing of routine or commoditized processes may also allow firms to specialize in areas of core competencies and leave those processes that involve strategic advantage as being knowledge-based processes to remain in-house. The danger of losing critical capabili-

ties through outsourcing is the risk of losing expertise, the reduction of absorptive capacity, and the loss of performance in the long term (Lahiri et al., 2022). KBV therefore points out that outsourcing is not merely concerned with cost reduction but also with the protection of competitive knowledge assets. The combination of TCE and KBV produces a two-level model: outsourcing is beneficial in the presence of a well-controlled cost of transaction when the core capabilities are not undermined. In its turn, bad decisions in either of the dimensions may lead to financial underperformance or strategic vulnerability (Neves et al., 2014; Charles and Ochieng, 2023).

This contingency view is supported by empirical research on the financial results of outsourcing. Lacity et al. (2011) showed that even though outsourcing can lead to cost savings, there are hidden costs and governance failures that negatively affect the expectation of benefits. Equally, Elia et al. (2014) demonstrated that the existence of strong contracts and monitoring systems can be the defining factor on whether outsourcing can improve the quality of services and cost savings, and poor governance has the propensity to worsen risks. Lahiri et al. (2022) further developed this point with the help of a meta-analysis and focused on the idea that financial gains are contingent upon the category of processes outsourced: transactional processes are usually associated with positive outcomes, whereas knowledge-heavy processes are likely to harm performance. These results reveal the pivotal position of managerial judgments to make opportunity choices and manage costs (Namadi, 2023).

Moreover, recent contributions have highlighted the complexity of outsourcing that is changing. Du and Miao (2022) claim that digitalization has revolutionized the relations of outsourcing so that it may be more integrated into governance, but it depends more on an external technological capability. As Le et al. (2025) point out, cultural distance and institutional voids continue to be a problem in emerging markets, which frequently result

in opportunism and confidentiality breaches as well as quality concerns. On the other hand, researchers also specify that outsourcing remains a critical choice that could help companies in emerging economies modernise and gain access to foreign knowledge and decentralise in global value chains (Mhillu, 2022; Sia et al., 2021). This two-sidedness, the concurrent search for efficiency, and the risk exposure, predispose managerial control of the selection of a vendor and control of costs to such decisiveness in such circumstances.

BPO is also being established as a policy-supported source of efficiency and innovation within the Gulf region, and Saudi Arabia in particular. Vision 2030 recognizes outsourcing as the means of developing more agile organizational frameworks, decreasing the dependence on government subsidies, and provoking competitiveness in the spheres of the government and the private sector (Moshashai et al., 2018; Moreau and Aligishiev, 2024). Traditionally, Saudi companies used vertical models and did not engage in much outsourcing (Ramady, 2010). The recent surge in outsourcing practices is thus not only a change in terms of operations, but also a cultural and strategic change. Outsourcing has come to be viewed as being in tandem with national modernization and allows companies to experience international best practices, digitalization, and a cheaper flexible cost base (Aziz and Sarwar, 2023; Alrawabdeh et al., 2023).

Although there has been this policy momentum, the empirical evidence on the financial results of BPO in Saudi Arabia is limited. Although there are anecdotal and descriptive reports, there are limited systematic reports that have critically assessed the performance implications of outsourcing at a firm level. This lack is dramatic considering the rate at which BPO is being adopted in organisations like Miza International Co., which has signed over fifty outsourcing agreements but is still experiencing inefficiencies, cost escalations, and customer dissatisfaction. These experiences indicate that the financial gains of outsourcing are falling short of expectations, and there is a mediating impact of managerial capability to facilitate the

outsourcing results and organizational objectives (Alrawabdeh et al., 2023).

This research disjuncture in Saudi-based research is reflective of existing constraints in outsourcing scholarship. A lot of empirical literature has focused on the Western and Asian economies, especially India and the Philippines, where outsourcing ecosystems have already developed. In comparison, little is known about the contexts in which institutional frameworks are weaker, the vendor markets are new, and cultural norms influence governance in different ways. Managerial activities turn that much more crucial in the context of these settings, where the potential benefits of outsourcing can be captured and the risks may be addressed (Elia et al., 2014; Le et al., 2025). The Saudi case, therefore, turns out to be not only a chance to examine local contexts but also a chance to broaden the global knowledge on how outsourcing operates in the light of emerging-market circumstances.

Critical evaluation of this literature shows that there are three coherent insights. To begin with, the financial advantages of outsourcing are conditional and depend on the governance practices, contractual design, and protection of the knowledge assets (Williamson, 1998; Grant, 1996; Lacity et al., 2011; Lahiri et al., 2022). Second, in developing nations, institutional deficiencies amplify the significance of managerial-level practices, especially in the process of selecting the vendor and controlling the costs, in either a successful or a failed outsourcing (Elia et al., 2014; Le et al., 2025). Third, although outsourcing is increasingly becoming popular under Saudi Vision 2030, few empirical studies have explored the impact of outsourcing on the financial performance of firms at the firm level in the Kingdom. To fill in this gap, there should be a framework that combines the cost management approach of TCE with the knowledge limits approach of KBV.

The current research based on this synthesis explores two practices in management as the key factors that determine the performance of outsourcing: BPO opportunities selection and outsourcing costs management. Opportunity selection is the decision to externalize which func-

tions to outsource, and it has been shown that routine functions and non-core functions are the most likely to be able to experience efficiency, whereas outsourcing knowledge-based functions or functions of strategic value may result in the loss of capabilities (Grant, 1996; Lahiri et al., 2022). Cost management, in its turn, involves managing and controlling the production costs and the transaction costs throughout the outsourcing lifecycle. Williamson (1998) also pointed out how unchecked transaction costs may cancel out savings, whereas Handley (2012) and recent research (Du and Miao, 2022) argue that it should be transparently monitored with flexible contracts and capable oversight.

On this theoretical and empirical background, this research is conducted based on two hypotheses:

- H_1 : *BPO opportunity selection is positively related to the financial performance.*
- H_2 : *The effective cost management of BPO has a positive relationship with better financial performance.*

The research has implications for theory and practice as it answers these hypotheses within the framework of a Saudi company. In theory, it narrows the gap between TCE and KBV in demonstrating the interactions of the dual logic between cost and knowledge in the emergent market outsourcing decisions. Empirically, it increases the geographic range of outsourcing research as it analyzes a region that is mostly not covered in the literature. In practice, it represents a guide to the managers and policymakers in Saudi Arabia and other similar economies, aiming to coordinate outsourcing policies with financial and developmental objectives.

3 METHODOLOGY

3.1 Research Design

The study is based on a single-case study design, which was descriptive, with Miza International Co. serving as a critical case a Saudi Arabian based company that has made significant investments in BPO and has been facing frequent operational and financial difficulties. This design was suitable in the comprehensive exploration of a complex phenomenon such as outsourcing in its distinct institutional and cultural setting (Yin, 2018), which is vital in a new economy such as Saudi Arabia.

The research had a quantitative dominant mixed-methods approach. The quantitative stream enabled the robust testing of hypothesis to be conducted with the use of statistical models whereas the qualitative framing offered the required depth to the context. The theoretical framework that formed the methodological orientation of the study and the operationalization of its constructs were based on a bilateral theoretical framework; the Transaction Cost Economics (TCE) (Williamson, 1998) and Knowledge-Based View (KBV) (Grant, 1996).

This two-lens rushed the chance to research on both cost-efficiency (TCE) and knowledge-transfer processes (KBV) as the stimulators of financial results.

3.2 Population of the Study and Sampling Strategy

The target population included the stakeholders of Miza International Co., directly or indirectly involved in outsourcing. This comprised both internal stakeholders within the five core functional departments- finance, operations, human resources, procurement, and administration and outside stakeholders, including outsourcing clients, contractors, and entrepreneurs, who interact with the outsourcing ecosystem of Miza. Since outsourcing involves cross-cutting across multiple functional and hierarchical levels, the participants encompassing various positions were intentionally chosen in order to exclude the risk of biasing towards one particular point of view.

The population included those stakeholders of Miza International Co. that were directly or indirectly involved in BPO. This involved internal and external stakeholders (outsourcing clients, contractors, and relevant entrepreneurs) meant that a stratified random sampling approach has been used to guarantee a proportional representation of the four major stakeholder groups according to their hierarchy of involvement: outsourcing clients (50%), company staff (20%), interested parties (20%) and entrepreneurs/others (10%). The standard statistical formulas were used to determine the minimum size of the sample at 95 percent confidence level and with a margin of error of 5 percent. In the end, 384 valid responses were received, and it gave enough statistical power to conduct multivariate analysis (Hair et al., 2019).

3.3 Data Collection

The information was gathered through a self-reported structured questionnaire. The tool is based on the current validated scales on

outsourcing literature but it was adjusted according to the contextual relevance to the Saudi market. The measures were measured through a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Clarity and face validity were verified with the help of pre-testing on 15 employees.

There were questions based on four main conceptual areas in the questionnaire. Most importantly, the independent variables were structured in the way that represented the dual theoretical framework (as seen in Tab. 1) and tested the hypotheses: The particular responses (Likert scores) that were directly related to the hypotheses through the formation of composite scores of the three main constructs. As an example, the high ratings in the questions of BPO Opportunities under Selection confirmed H₁, which states that strategic selection generates financial performance.

Tab. 1: Operationalization of Study Constructs and Alignment with Theoretical Frameworks (TCE and KBV)

Construct	Alignment	Measurement Components (Items)	Role in Hypothesis
Financial Impact of BPO (Dependent Variable)	Perception	Perceived financial outcomes (e.g., ROI, profit growth). Measured as stakeholder perception.	Measures the overall success outcome.
Selection of BPO Opportunities (Independent Variable)	KBV / Strategic	Strategic Goals, Service Quality, Shares Risks with Vendor.	Tests H ₁ : BPO selection (strategic alignment/quality) to Financial performance.
Cost Management in BPO (Independent Variable)	TCE / Efficiency	Reduces Operating Costs.	Tests H ₂ (TCE core): Cost management to Financial performance.
Knowledge and Expertise (Independent Variable)	KBV (Core Construct)	Knowledge about BPO (e.g., expertise acquisition, BPO method awareness).	Critical Clarification (Addressing Review 2, Point 4): Although statistically tested with the cost item for internal consistency (as reported in Section 4.2), this construct is the primary measure for the KBV tenet strategic knowledge acquisition and its coefficient is interpreted as supporting KBV, not TCE.

3.4 Analytical Procedures

Data analysis was done through SPSS Version 28. The statistical tests were conducted as follows:

- *Descriptive Statistics*: Summed up sample scores (means, standard deviations) and preliminary perceptions.
- *Reliability Tests*: Cronbach's Alpha was applied to determine the high internal consistency of all constructs wherein the scores of the independent variables exceeded the acceptable figure of 0.70 (Nunnally and Bernstein, 1994).
- *Inferential Tests*: Both the bivariate relationship between the constructs and the dependent variable (Financial Impact of BPO) was tested using Pearson correlation analysis.
- *Hypothesis Testing*: Multiple Linear Regression (MLR) was employed to quantify the predictive power of the independent variables (BPO selection and cost management/knowledge) on the dependent variable (Financial Impact of BPO).

Furthermore, independent-samples *t*-tests and ANOVA are used as inferential statistics to evaluate the group differences between departments and roles, and Pearson correlation was used to evaluate the relationship between the outsourcing practices and the financial outcomes. In addition, Correlation analysis is used to test the hypotheses of the study. Financial performance was taken as a dependent variable, and BPO selection and cost management were taken as independent variables, whereby the predictive power of the two managerial capabilities highlighted in the theoretical framework was quantified.

4 RESULTS

The survey produced 384 valid responses from the stakeholders in Miza International Co., who are outsourcing clients, employees, business startups, and so on. The findings are provided in four steps: descriptive statistics, reliability testing, correlation, and regression modeling.

3.5 Ethical Considerations

The research was conducted in accordance with all ethical standards: informed consent to take part in the study was collected, participation was optional, anonymity and confidentiality were guaranteed. The methodology was selected because of the requirements of the statistical rigor and contextual validity. The single-case study with a powerful quantitative research ($N = 384$) and stratified sampling gives a holistic and reliable empirical foundation to draw conclusions on the financial impact of the BPO in the specific reform-based setting in Saudi Arabia.

3.6 Methodological Rationale

The two factors that guided the methodological decisions are the necessity of statistical rigor and the necessity of contextual validity. The case study design provides a comprehensive cognizance of the outsourcing practices in a fast-evolving Saudi environment, and the structured questionnaire and stratified sampling of 384 stakeholders added to the representativeness and trustworthiness of the research. Similarly, measurement quality is ensured by the use of validated constructs and Cronbach's Alpha, which are higher than the recommended value. The use of SPSS facilitated the use of regression modeling, which enhanced the test of hypotheses and yielded academic and managerial results. The methodology, in general, enabled the empirical-based inferences about the financial implications of the BPO and helped to enhance knowledge about outsourcing in the emerging economies and align with the goals of Saudi Arabia's Vision 2030.

These analyses are evidence of testing the two hypotheses:

- H_1 : *BPO opportunity selection is positively related to the financial performance.*
- H_2 : *BPO financial performance is positively related to effective cost management in BPO.*

4.1 Descriptive Statistics

The descriptive statistics give the impression of an overview of how the stakeholders perceived outsourcing practices and results. The findings showed that there were positive attitudes towards BPO, especially in the areas of cost effectiveness, strategic alignment, and financial impact. Mean score of Financial Impact was 3.39 (SD = 0.681), indicating that the respondents view BPO as being moderately to strongly helpful to financial performance. There were similar levels of Reduces Operating Costs (M = 3.36, SD = 0.682) and Contributes to Strategic Goals (M = 3.44, SD = 0.619), which suggests a focus on both the economic and strategic goals.

However, interestingly, the likelihood to recommend BPO scored high (M = 3.40, SD = 0.662), hence posing a positive spillover effect like reputation and internal advocacy. Conversely, negative risks (loss of process control, M = 2.69, SD = 0.462) and negative risks (Unable to resolve conflicts, M = 2.74, SD = 0.437) were rated lower, meaning that they are perceived as secondary obstacles. These analytical conclusions underscore the fact that outsourcing is normally viewed as a constructive driver towards cost effectiveness and strategic fit, though the existence of threats moderates impetuous anticipation. The most

important descriptive findings are summarized in Tab. 2.

4.2 Reliability Analysis

The internal consistency of the measurement tools was tested to prove that the constructs applied in this study were reliable and stable before testing the hypotheses. The two main constructs of interest in relation to the BPO Opportunities and Cost Management have been computed as the Alpha of Cronbach's. A Cronbach's Alpha of 0.70 or more is usually regarded as an acceptable threshold of reliability, which means that the items in a construct all measure the same underlying concept in similar way (Nunnally and Bernstein, 1994).

These findings affirmed that the two constructs had adequate levels of reliability. The construct, Selection of BPO Opportunities, that encompassed the items StrategicGoals, ImproveQuality, and ShareRisks, had a Cronbachs Alpha of 0.773. This indicates a high level of internal consistency in the items that were employed to measure the effectiveness with which the opportunities of outsourcing were spotted and matched with the organizational objectives. In the same manner, Cost Management in BPO, which is a set of three variables, ReduceCosts, Knowledge, and Financial Impact, produced

Tab. 2: Descriptive statistics of key variables

	N	Minimum	Maximum	Mean	Std. Deviation
Stakeholder Group	384	2	4	2.93	0.657
Knowledge about BPO	384	2	4	3.41	0.641
Financial Impact of BPO	384	2	4	3.39	0.681
Reduces Operating Costs	384	2	4	3.36	0.682
Contributes to Strategic Goals	384	2	4	3.44	0.619
Improves Service Quality	384	2	4	3.38	0.698
Cronbach's	384	2	4	3.40	0.662
Lack of Communication	384	2	3	2.76	0.431
Loss of Process Control	384	2	3	2.69	0.462
Inability to Resolve Conflict	384	2	3	2.74	0.437
Low Quality of Services	384	2	3	2.73	0.442
Minimal Knowledge of BPO Methods	384	2	3	2.72	0.449
Likelihood to Recommend BPO	384	2	4	3.40	0.662
Valid N (listwise)	384				

Tab. 3: Reliability statistics for study constructs

Construct	Items	Cronbach's Alpha	Number of Items
Selection of BPO Opportunities	Strategic_Goals, Improve_Quality, Share_Risks	0.773	3
Cost Management in BPO	Reduce_Costs, Knowledge, Financial_Impact	0.765	3

Cronbach's Alpha of 0.765. This value is also higher than the recommended value, which is a confirmation that the items are always relevant to the degree to which the consideration of costs and knowledge of outsourcing practices determines financial outcomes.

These reliability values are comparable with previous findings in the literature on the outsourcing subject when compared with the existing global studies. As an example, Lacity et al. (2009) reported Cronbach's Alpha of 0.72–0.81 when using this measure to investigate the outsourcing decision-making process in MNCs, and Sharma and Loh (2009) also found values of reliability coefficients higher than 0.75 in their cross-national study of BPO success factors. The current findings, hence, not only support but also exceed known standards within the research on outsourcing globally, indicating that the scales of measurement used in the research are both strong and cross-culturally relevant. When combined, the results show that the two constructs are both consistent and can be used in a later inferential test, like correlation and regression analysis. Tab. 3 gives the statistics on the reliability.

4.3 Correlation Analysis

Pearson correlation coefficients were determined to investigate the bivariate relationships of the study constructs. The findings of the correlation analysis are shown in Tab. 4 and suggest that all the key variables are significantly and positively correlated at the level of 0.01. This implies that there is a stable trend in the association of business process outsourcing (BPO) practices and perceived financial impact.

The findings indicate that the selection of BPO Opportunities- embodied in Contributes to Strategic Goals, Improves Service Quality, and shares risks with Vendor is highly associated with the financial results of BPO. In

particular, contributing to Strategic Goals has a significant positive relationship with Financial Impact ($r = 0.564, p < 0.001$). This means that the stakeholders see BPO improving financial performance when the outsourcing initiative is strategically aligned with organizational goals. On the same note, Improves Service Quality ($r = 0.544, p < 0.001$) and Shares Risks with Vendor ($r = 0.543, p < 0.001$) also have moderate-to-strong positive relations with financial performance. Combined, these findings emphasize the fact that one must not choose outsourcing opportunities only based on the cost factor alone, but also depending on the fact that it can help improve competitiveness and minimize operational weaknesses.

When it comes to Cost Management in BPO, both Reduces Operating Costs ($r = 0.537, p < 0.001$) and Knowledge about BPO ($r = 0.514, p < 0.001$) are positively correlated with Financial Impact, but in all cases, in a statistically significant manner. It means that successful cost management and higher awareness of the execution of outsourcing are connected with better financial results. It is worth noting that the relationship between reducing operating Costs and financial performance is one of the strongest ones, which confirms the TCE view that effective contractual and operational cost management is one of the factors that lead to efficiency gains at the firm level. Additionally, Likelihood to Recommend BPO is positively interconnected with all other constructs, in particular, with Contributes to Strategic Goals ($r = 0.568, p < 0.001$) and Reduces Operating Costs ($r = 0.548, p < 0.001$). The observation is important in that, as long as the stakeholders see outsourcing as a source of strategic alignment and cost-efficiency, they will be more likely to support its further utilization in the organization.

In terms of robustness, most of the correlations are larger than 0.50, which is a strong

Tab. 4: Pearson correlation matrix

		Financial Impact of BPO	Contributes to Strategic Goals	Improves Service Quality	Shares Risks with Vendor	Reduces Operating Costs	Knowledge about BPO	Likelihood to Recommend BPO
Financial Impact of BPO	Pearson Corr.	1	.564**	.544**	.543**	.537**	.514**	.554**
	Sig. (2-tailed)		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	N	384	384	384	384	384	384	384
Contributes to Strategic Goals	Pearson Corr.	0.564**	1	0.531**	0.511**	0.518**	0.501**	0.568**
	Sig. (2-tailed)	< 0.001		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	N	384	384	384	384	384	384	384
Improves Service Quality	Pearson Corr.	0.544**	0.531**	1	0.555**	0.532**	0.523**	0.499**
	Sig. (2-tailed)	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	< 0.001
	N	384	384	384	384	384	384	384
Shares Risks with Vendor	Pearson Corr.	0.543**	0.511**	0.555**	1	0.531**	0.518**	0.505**
	Sig. (2-tailed)	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001
	N	384	384	384	384	384	384	384
Reduces Operating Costs	Pearson Corr.	0.537**	0.518**	0.532**	0.531**	1	0.510**	0.548**
	Sig. (2-tailed)	< 0.001	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001
	N	384	384	384	384	384	384	384
Knowledge about BPO	Pearson Corr.	0.514**	0.501**	0.523**	0.518**	0.510**	1	0.548**
	Sig. (2-tailed)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		< 0.001
	N	384	384	384	384	384	384	384
Likelihood to Recommend BPO	Pearson Corr.	0.554**	0.568**	0.499**	0.505**	0.548**	0.548**	1
	Sig. (2-tailed)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	
	N	384	384	384	384	384	384	384

Note: Correlation is significant at the 0.01 level (2-tailed).

association, but not one of them exceeds the 0.80 mark, which is a generally problematic multicollinearity threshold (Hair et al., 2019). This implies that the constructs are not redundant, though they are interrelated, and thus their usage as independent predictors in future regression analysis. On the whole, the results of correlation support the two hypotheses (H_1) that effective BPO opportunity selection is positively correlated with the financial performance, and (H_2) that the effectiveness of cost management in BPO arrangements is correlated with the financial outcomes. The fact that the correlations between variables were relatively high and consistent also implies that the decisions made at BPO at Miza International Co. are interrelated, and strategic and cost factors influence the perceptions of financial impact together.

4.4 Regression Analysis

In order to formally test the hypotheses, a multiple linear regression model was estimated to provide the Financing Impact of BPO with five predictors, including Contributes to Strategic Goals, Improves Service Quality, Shares Risks with Vendor, Reduces Operating Costs, and Knowledge about BPO. The statistical significance of the model was $F(5, 378) = 68.402$, $p < 0.001$, and the model had a value of $R^2 = 0.475$. This implies that the predictor set explains the variation in perceptions of financial performance when the set is used as a whole (i.e., 47.5 percent), which is a good outcome in organizational research in a single-firm environment. Contributes to Strategic Goals turned out to be the most powerful predictor among the independent variables ($b = 0.234$, $p < 0.001$). This finding highlights the notion that outsourcing is seen to positively impact financial performance in the most efficient way

Tab. 5: Multiple regression results for hypothesis testing-model summary

Model	<i>R</i>	<i>R</i> ²	Adjusted <i>R</i> ²	Std. Error of the Estimate	<i>R</i> ² Change	Change Statistics			Sig. <i>F</i> Change
						<i>F</i> Change	df1	df2	
1	0.689 ^a	0.475	0.468	0.496	0.475	68.402	5	378	< 0.001

Note: ^a) Predictors: (Constant), Knowledge about BPO, Contributes to Strategic Goals, Reduces Operating Costs, Shares Risks with Vendor, Improves Service Quality

in case it is strategically related to long-term organizational goals, which confirms H₁. On the same note, Reduces Operating Costs (*b* = 0.168, *p* = 0.001) and Knowledge about BPO (*b* = 0.137, *p* = 0.005) were also significant positive predictors, which give H₂ empirical support. These results in Tab. 5 validate the fact that cost effectiveness and experience built up concerning the outsourcing procedures can bring tangible financial benefits to the firm.

Interestingly, the other significant contribution to the model was Improves Service Quality (*b* = 0.163, *p* = 0.001) and Shares Risks with Vendor (*b* = 0.173, *p* < 0.001), which were not initially included in the hypotheses. Their presence offers more support to the fact that there are relational and service-related aspects of BPO that, in addition to the cost and strategy, influence the financial performance. This is in line with the perspective of the knowledge-based view (KBV) that highlights the relational capabilities and knowledge-sharing in inter-organizational partnerships. The regression coefficients in Tab. 6 show that there are no negative or insignificant coefficients at all, and all the predictors are statistically significant at the 0.01 level. Besides, the adjusted *R*² of 0.468 indicates that the model has explanatory

robustness despite the consideration of the sample size and predictors.

Overall, both hypotheses are true and their results are supported by the regression results, which, in addition, demonstrate that relational and quality-enhancing elements of BPO also play a significant role in influencing financial performance. Collectively, these findings indicate that the success of outsourcing in the Saudi situation cannot be narrowed down to mere cost-saving, but the strategic alignment, cost discipline, service quality, risk sharing, as well as integration of knowledge, all play a role in determining the financial consequences of BPO solutions.

To supplement the regression findings, a graphical summary was formulated to be used to depict the perceptions of the respondents about the financial effects of BPO. A bar chart was used in Fig. 1 to examine the responses of Financial Impact. The findings show that 29.2% of the respondents assigned the financial impact to be VH (5), and 27.1% assigned it to be H (4). This is a huge positive perception by 56.3 percent of respondents, indicating that over 50 percent of employees have noticed significant financial gains linked with BPO practices at Miza International Co. This graphical analysis

Tab. 6: Multiple regression results for hypothesis Testing-Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients		
		<i>B</i>	Std. Error	Beta	<i>T</i>	Sig.
1	(Constant)	0.306	0.170		1.797	0.073
	Contributes to Strategic Goals	0.257	0.053	0.234	4.815	< 0.001
	Improves Service Quality	0.159	0.049	0.163	3.248	0.001
	Shares Risks with Vendor	0.177	0.051	0.173	3.469	< 0.001
	Reduces Operating Costs	0.167	0.049	0.168	3.412	< 0.001
	Knowledge about BPO	0.146	0.051	0.137	2.833	0.005

Note: Dependent Variable: Financial Impact of BPO

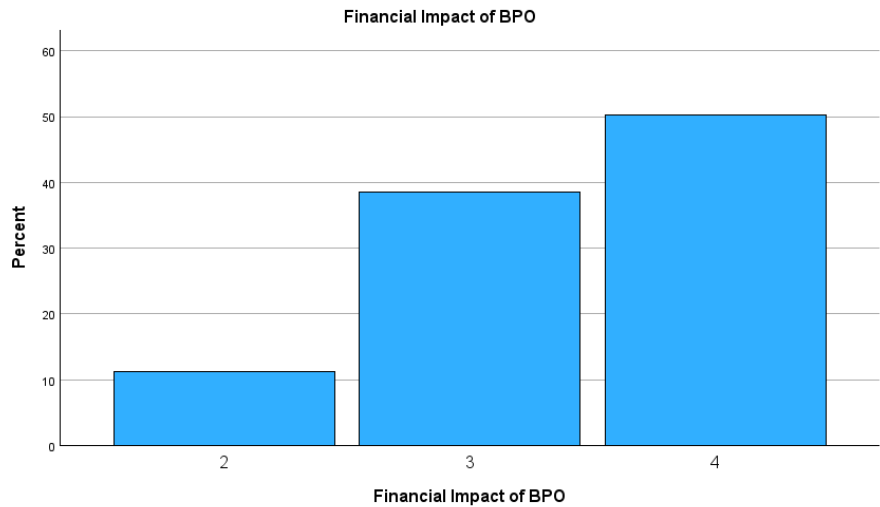


Fig. 1: Distribution of Perceived Financial Impact of BPO

supports the results of statistical analysis by pointing out the prevailing pattern of positive perceptions that also supports the presence of BPO as a value-adding practice within the organization.

4.5 Summary of Results

Miza international Co. stakeholders completed 384 valid of the study, and the preliminary descriptive data analysis showed that there was a high positive perception of BPO, with the mean score of Financial Impact ($M = 3.39$), contributes to strategic goals ($M = 3.44$); reduces operating cost ($M = 3.36$) having a moderate-strong positive perception. Internal consistency of the constructs was tested through reliability testing, and the results of Cronbachs Alpha of 0.773 of Selection of BPO Opportunities and Cronbachs Alpha of Cost Management in BPO is 0.765. It was determined that the

correlation analysis demonstrated stable and significant positive relationships between all the key variables and Financial Impact ($r > 0.5$), and it has been indicated that BPO practices are highly interrelated in this firm. The multiple linear regression model was found to be statistically significant – $F(5,378) = 68.402$, $p < 0.001$ – and explained the variation in perceived financial performance at 47.5%. Both main hypotheses were justified. The quality of BPO selection was highly encouraged, and Contributes to Strategic Goals was the most powerful predictor of quality ($b = 0.234$, p is not significant). The importance of Reduces Operating Costs ($\beta = 0.168$, $p < 0.001$) and Knowledge about BPO ($\beta = 0.137$, $p = 0.005$) also contributed to the effectiveness of cost management. Moreover, the relational variables, Shares Risks with Vendor and Improves Service Quality were also found to be significant positive contributor.

5 DISCUSSION

The results indicate that both the strategic choice of BPO opportunities and the practice of disciplined cost management aids significantly to the financial performance of Miza International Co., one of the leading enterprises

that operates in the Saudi Arabian market. Considered through the prism of the concept of Transaction Cost Economics (TCE) and the Knowledge-Based View (KBV), the findings provide a solid argument in favor of Hypothesis

H1 as it reveals that strategic alignment is not limited to the reduction of costs but it also relates to the enhancement of organizational learning, building the capabilities, and maintaining the competitiveness. Notably, the fact that the factor of Strategic Goal Contribution became the strongest predictor ($b = 0.234$) requires mention. This implies that BPO in Miza International Co. is not viewed as an efficiency-oriented or sole initiative but as a strategic tool of developing the capability and creating value beyond short-term financial benefits.

This observation is quite consistent with the KBV argument that sustainable competitive advantage is based on integration and effective use of specialized external knowledge. In the context of the more general vision of Saudi Arabia, Vision 2030, in which the emphasis is placed on the economic diversification, privatization, and efficiency of operation, the focus on the strategic fit rather than merely cost reduction seems rather logical. Companies in such a reform-friendly environment need to use BPO to develop new competencies, to achieve international standards and to modernise operations as opposed to working on minimal cost reduction in the short term. This strategic orientation is the opposite of what can be more often seen in Western mature outsourcing markets where reducing the costs often predominates outsourcing justification and performance indicators.

It also proves hypothesis H₂ to be correct, and it is supported by the important effect of Reduces Operating Costs ($b = 0.168$), which confirms the applicability of TCE continues to be relevant today. Outsourcing agreements lead to lowered transaction costs and governance risks and greater operational efficiencies that are translated into financial benefits that can be quantified. Nevertheless, the importance of the variable of Knowledge about BPO ($b = 0.137$) implies that transactional efficiency is not sufficient in explaining the success of outsourcing. Even though the statistical clusters of knowledge development and absorptive capacity are placed in the same construct of cost management due to their reliability of the construct, the two are essentially consis-

tent with the KBV. The positive correlation shows that the organizational knowledge in selected vendors, management of contracts, and knowledge integration is also a crucial non-cost determinant of financial performance. Combined, the results confirm the usefulness of a dual-framework approach, in the sense that both transactional efficiency (TCE) and strategic capability building (KBV) act in a complementary way and activate each other in the creation of outsourcing results.

This integrative interpretation is reinforced by the fact that the value of Shares Risks with Vendor ($b = 0.173$) is significant. Risk-sharing agreements indicate the relational governance mechanisms that are used to cope with uncertainty and encourage collaborative partnership forms. These management skills are particularly crucial in the Saudi environment, whereby the regulatory environments and local networks of suppliers are yet to be established. The comparatively low average perception risk scores, including the lack of control of the processes and the inability to resolve the conflict situation, indicate that the Miza International Co. has managed to engage in the practice of relational contracting that would help to avoid the most frequent outsourcing traps. These findings support the previous studies highlighting the role of the strength of governance and the relational management in the new economy (Lahiri et al., 2022).

On the macro level, the findings are very applicable to the Saudi economic transformation agenda. The pillars of national development as promoted by the vision 2030 encompass the promotion of privatization and digitalization and productivity, and BPO becomes a convenient tool that will allow firms to improve the performance of departments and at the same time become contributors to the overall national goals. As with existing evidence, institutional maturity does not seem to be the key determinant of outsourcing success in the developing economies but, rather, a firm-level managerial competence (Lahiri et al., 2022). The case of Miza International Co. that functions in a regulatory environment that is still developing illustrates the significance of

governance competence, relationship contracting, and monitoring of vendors in maintaining financial gains.

However, there are still some issues that can be observed. Having moderate mean scores in the categories of communication gaps, less control process and conflict resolution (between 2.69 and 2.76) also bring out the vulnerabilities inherent to outsourcing in emerging markets. These are analogous to the results of Elia et al. (2014), who emphasized the decisive role of governance mechanisms in defining the success of outsourcing, and Amoozegar et al. (2025), who highlighted the necessity of the perpetual investment in the development of relational governance and internal capabilities to avoid the risks of dependency. Simultaneously, the

high positive relationships between the intention to recommend BPO and strategic selection ($r = 0.568$) and cost management ($r = 0.548$) mean that the outsourcing practices are widely accepted in the organizations. This internal support minimizes cultural resistance and helps to implement it easier, which, according to Cabral et al. (2013), is one of the barriers that are especially important in the non-Western environment.

In general the discussion shows how cost efficiency does not serve as a driving force of outsourcing effectiveness in the Saudi Arabian context but a balanced interaction between strategic alignment, transactional discipline, knowledge integration, and relational governance.

6 CONCLUSION AND RECOMMENDATIONS

This paper explored financial performance of BPO at Miza International Co., showing that judicious choice of opportunities and effective cost management are both the significant factors of financial performance. The regression model expounded 47.5% of the financial results, and the five most important predictors, that is, contributes to Strategic Goals (maximum), Improves Service Quality, Shares Risks with Vendor, Reduces Operating Costs, and Knowledge about BPO, demonstrated their positive and significant contributions to the financial results. The results are very helpful to prove the practicality of a two theoretical approach (TCE and KBV): BPO is not only a cost-cutting strategy but the strategic skill that boosts organizational learning and long-term competitiveness in a new economy.

6.1 Limitations and Future Research

Although strong, there are two major limitations of this study. To start with, the dependent variable is solely based on stakeholder perception of financial impact (Likert scale) as opposed to objective financial measures (e.g. ROI, cost savings ratios). This creates the possibility of subjective bias. Second, the study

is not able to sufficiently prove causality due to the cross-sectional survey design. Reverse causality may influence the results where the perceived high financial performance may cause the stakeholders to rate the managerial practices (independent variables) more positively. Future studies must overcome these limitations by using objective financial information and using longitudinal designs to achieve a better causating factor.

6.2 Managerial and Policy Recommendations

According to the findings, the phenomenon of BPO should be treated by Saudi companies on a long-term strategic basis:

1. *Strategic Alignment*: Assure that all the outsourcing projects are directly aligned with strategic organizational intent and national objectives including those related to efficiency and innovation described in Vision 2030.
2. *Capability Building*: Invest in enhancing knowledge and good vendor governance to avoid the unseen costs and to transfer knowledge as much as possible.

3. *Relational Governance*: Develop true partnerships with vendors to support the effective risk-sharing, reduce the number of

communication gaps, and solve the issues of the process control with mutual trust and performance monitoring.

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ORGANIC/BIO FOOD LABELLING SYSTEMS AND THEIR PERCEPTION BY CZECH CONSUMERS WITH A FOCUS ON ECOLOGY

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ABSTRACT

The importance of organic products in the Czech Republic as an EU member state is growing. Among other things, increasing the share of organic products in relation to conventional products is one of the long-term objectives of the European Community. The research carried out focused on examining differences in consumer purchasing behaviour, specifically the associations that consumers most often associate with brands that label bio/organic products in the Czech Republic. Using various statistical methods, the knowledge and perception of organic/bio products labelled with the Czech and European logos was investigated. The research shows that consumers most often associate products bearing the Czech label with ecology and environmental friendliness. Respondents often associate this labelling with higher quality and at the same time subjectively perceive the food as healthier. The European organic food label is most often associated with ecology and environmental friendliness, higher quality and perceived as healthier by respondents. Respondents show significantly higher ignorance of this label than the national label.

KEY WORDS

sustainable food and agriculture, ecological consumer behaviour, ecological products, organic/BIO products, Czech and European organic/BIO labels, sustainable environment

JEL CODES

C12, C30, C35, C83, M31

1 INTRODUCTION

Increasing the share of organic products in relation to conventional products, including the promotion of their production in the field of organic farming and food processing, is one of the long-term objectives of the European

Community. Therefore, the importance of organic products on the European market is very topical and the market for organic products in the European Union has been growing continuously for several decades, with the largest

growth period experienced by this sector in 1997–2006, when the increase in the volume of organic food produced was 80% (Ditschun, 2010). The United States of America has the dominant share of the global market for organic streams (42%), followed by Germany (11%) and France in third place (9%), see Statista (2021), Lockeretz (2011), Lockie et al. (2002). Thus, Europe profiles as the second largest market for organic products in the world (Kristiansen et al., 2006; Willer et al., 2021).

The market for organic products is also on the rise in the Czech Republic, with the total market volume of these organic products in the Czech Republic exceeding CZK 4 billion in 2016 (Institute of Agricultural Economics and Information, 2021; Janssen and Hamm, 2012). The total consumption of organic products by consumers in the Czech Republic was then CZK 2.55 billion. In the same year, for example, there were 50% more producers of organic products in the Czech Republic than in 2009 (Czech Union of Commerce and Tourism, 2021). In 2019, the total consumption of bio-products among consumers was CZK 3.73 billion (Czech Ministry of Agriculture, 2019). The most popular bio-products among Czech consumers are milk and dairy products and fruit and vegetables, with processed foods such as coffee, tea, spices, and baby food and feeds coming in third place (Czech Union of Commerce and Tourism, 2021).

In terms of consumption behaviour in relation to organic products, Kareklas et al. (2014) or Yadav (2016) identify two main reasons for purchasing products labelled organic/BIO. The first reason for purchasing food labelled in this way is primarily organic. The second main reason is to purchase these products because of subjectively perceived higher quality and potential health benefits (Dimitri and Dettmann, 2012).

One of the primary indicators of subjective quality of products is the labelling system, which provides consumers with critical information about the products they purchase (Martini and Menozzi, 2021; Aschemann-Witzel and Zielke, 2017). To assist consumers in making informed decisions, policymakers worldwide have implemented various strategies, including food

quality schemes, quality labelling (Jürkenbeck, 2023; Padel and Foster, 2005), and origin labelling (Garnier and Bilen, 2025; Grunert, 2005), as well as food systems focused on sustainability (Bauer et al., 2013; Krystallis and Chrysosoidis, 2005). The food quality labelling system, as discussed by Jürkenbeck (2023), plays a vital role in protecting traditional agricultural products and foodstuffs, particularly within the European context. The European food labelling system aims not only to protect consumers from false or misleading information regarding the origin of agricultural products but also to shield producers from anti-competitive practices (Martini and Menozzi, 2021; Grunert and Aachmann, 2016). Jürkenbeck (2023) and Bauer et al. (2013) argue that such labelling promotes the diversity of agricultural production, enhances the competitiveness of farmers and traditional producers, and informs consumers about the specific characteristics of labeled products. For consumers, labels that are protected by regulatory frameworks are a guarantee of quality and tradition.

1.1 Consumer Behavior Toward Organic Production Labels in the Czech Republic

Consumer behavior toward organic/BIO products, particularly in the Czech Republic, reflects a growing concern for ecological sustainability and health. BIO labels, such as the “Biozebra” and EU organic labels, are critical tools for consumers aiming to make environmentally conscious purchasing decisions. Research indicates that consumers in the Czech Republic, similar to global trends, increasingly prioritize the ecological impact of their food choices (Stolz et al., 2011; Bezawada and Pauwels, 2013). This shift is driven by a rising awareness of environmental issues, such as climate change, biodiversity loss, and the overuse of pesticides in conventional agriculture (Jürkenbeck, 2023; Martini and Menozzi, 2021; McCarthy et al., 2016).

According to Garnier and Bilen (2025), the ecological aspect of BIO products is a significant factor in consumer decision-making.

The demand for BIO products is partly fueled by the belief that organic farming practices contribute to environmental sustainability by reducing greenhouse gas emissions, preserving soil health, and promoting biodiversity (Bauer et al., 2013; Pino et al., 2012). Moreover, consumers who prioritize environmental considerations are more likely to trust and prefer products with recognized organic labels, as these labels assure adherence to stringent ecological standards (Martini and Menozzi, 2021; Grunert et al., 2014).

In addition to ecological concerns, other factors such as price, perceived prestige, and support for local producers also play a crucial role in shaping consumer behavior toward BIO products (Stolz et al., 2011; Printezis and Grebitus, 2018; Hughner et al., 2007). Price sensitivity remains a significant barrier, as Organic/BIO products are often priced higher than their conventional counterparts due to the more resource-intensive methods of organic farming (Jürkenbeck, 2023; Magnusson et al., 2003). However, for a segment of consumers, the perceived health benefits, along with the environmental impact, justify the higher cost (Bauer et al., 2013; Yiridoe et al., 2005).

1.2 The Ecological and Health Significance of Organic Products

Organic/BIO products are often heralded for their potential environmental benefits, including the reduction of greenhouse gases (GHGs) and nitrogen oxide emissions, the promotion of soil and water conservation, and the enhancement of biodiversity (European Commission, 2020; Crowder and Reganold, 2015; Saba et al., 2003). Organic farming practices, which underpin BIO product labelling, are designed to work in harmony with natural ecosystems, reducing the reliance on synthetic chemicals and promoting sustainable land use (Jürkenbeck, 2023; Seufert and Ramankutty, 2017; Tuck et al., 2014). However, the health benefits of BIO products are a subject of ongoing debate in the scientific community (Varzakas and Antoniadou, 2024; Martini and Menozzi, 2021). While some studies suggest that organic

foods may have higher nutritional content and lower levels of pesticide residues (Barański et al., 2014; Mie et al., 2017), others argue that the health advantages of BIO products are not significantly different from those of conventional foods (Garnier and Bilen, 2025; Dangour et al., 2009).

1.3 Consumer Behavior Toward BIO Labels in the Czech Republic

Consumer behavior toward Organic/BIO products, particularly in the Czech Republic, reflects a growing concern for ecological sustainability and health. Organic/BIO labels, such as the Biozebra and EU organic labels, are critical tools for consumers aiming to make environmentally conscious purchasing decisions (Vávrová and Beran, 2025). Research indicates that consumers in the Czech Republic, similar to global trends, increasingly prioritize the ecological impact of their food choices (Stolz et al., 2011; Bezawada and Pauwels, 2013). This shift is driven by a rising awareness of environmental issues, such as climate change, biodiversity loss, and the overuse of pesticides in conventional agriculture (Jürkenbeck, 2023; McCarthy et al., 2016).

According to Garnier and Bilen (2025), the ecological aspect of Organic/BIO products is a significant factor in consumer decision-making. The demand for Organic/BIO products is partly fueled by the belief that organic farming practices contribute to environmental sustainability by reducing greenhouse gas emissions, preserving soil health, and promoting biodiversity (Bauer et al., 2013; Pino et al., 2012). Moreover, consumers who prioritize environmental considerations are more likely to trust and prefer products with recognized organic labels, as these labels assure adherence to stringent ecological standards (Martini and Menozzi, 2021; Grunert et al., 2014).

In addition to ecological concerns, other factors such as price, perceived prestige, and support for local producers also play a crucial role in shaping consumer behavior toward BIO products (Stolz et al., 2011; Printezis and Grebitus, 2018; Hughner et al., 2007). Price

sensitivity remains a significant barrier, as Organic/BIO products are often priced higher than their conventional counterparts due to the more resource-intensive methods of organic farming (Jürkenbeck, 2023; Magnusson et al., 2003). However, for a segment of consumers, the perceived health benefits, along with the environmental impact, justify the higher cost (Bauer et al., 2013; Yiridoe et al., 2005).

1.4 Aim and Motivation

The primary objective and motivation of this article is to explain and compare consumer behavior toward two specific Organic/BIO labels in the Czech Republic—Biozebra and EU organic labelling by Czech customers. This comparison aims to understand how these labels influence consumer choices, with a particular

focus on the ecological and health considerations that drive the purchase of BIO products. Additionally, the article examines the broader implications of bioproduction on society, the environment, and the economy, aiming to provide insights that could guide state, industry and SME stakeholders in keeping and extending sustainable agricultural and food practices.

The following research questions were analyzed as part of the study:

- Does knowledge of Czech and European labelling of organic products depend on selected sociodemographic indicators?
- What attributes do consumers most often associate with organic products labeled with both Czech and European labelling?
- How does the perception of these attributes differ among respondents based on age, gender, and education?

2 METHODOLOGY AND DATA

This research compared the recognition of labelling systems and analysed the perception of different notions associated with the brands of organic products on both national and European level among the consumers in the Czech Republic and their dependence on selected socio-demographic indicators. As part of the research, a total of 982 responses from Czech respondents were included in further processing. This is a quota selection; individual categories are listed in Tab. 1. Respondents from the youngest generation, Generation Alpha, were grouped together with Generation Z respondents. No respondents from the Beta and Silent Generations participated in the study. The research was conducted in 2024 via an online questionnaire.

The methods of logistic regression, analysis of contingency tables, correspondence maps, and analysis of variance were chosen for the analysis of the obtained data. Logistic regression allows for the detection of factors influencing whether the observed phenomenon occurs and to assess the level of their influence. These can include both numerical and categorized variables, such as selected socio-demographic indicators – age,

gender, and consumer education. It is then possible to estimate in individual cases the probability of the observed phenomenon based on the values of these explanatory variables.

Individual sub-dependencies of the selected questions on socio-demographic variables (gender, age, education) were analysed with the use of contingency tables. Correspondence analysis is a popular graphical technique enabling the analysis of relations between the categories of one or more variables in contingency tables. Using the tools of correspondence analysis, it is possible to describe the associations of nominal or ordinal variables in different categories of variables and to obtain a graphical representation of the relationships in a multidimensional space.

Additionally, in order to compare the results between different citizen groups, the authors employed analysis of variance.

The Kruskal–Wallis test by ranks is a non-parametric method for testing whether samples originate from the same distribution. It is used for comparing two or more independent samples of equal or different sample sizes. It extends the Mann–Whitney *U* test when there are

Tab. 1: Sample of respondents

Country	Variables	Values	Percentage
Czech Republic	Sex	Women	47.66%
		Men	52.34%
	Age	Generation Z (1997 and later)	25.87%
		Generation Y (1982–1996)	26.07%
		Generation X (1965–1981)	24.95%
		Baby boomers (1946–1964)	23.12%
	Education	Primary	14.77%
		Secondary	28.11%
		Secondary with high school diploma	32.79%
		Tertiary	24.34%

only two groups. Null hypothesis assumes Null hypothesis assumes that the mean ranks of the groups are the same. It can be used as an alternative to the parametric one-way analysis of variance (ANOVA) when the population cannot be assumed to be normally distributed. The Kruskal–Wallis test can be used for ranked or ordinal data. A significant Kruskal–Wallis test indicates that at least one sample stochastically dominates one other sample. The test does not identify where this stochastic dominance occurs or for how many pairs of groups stochastic dominance obtains.

Test statistic with asymptotically χ^2 distribution with $c - 1$ degrees of freedom is

$$H = \left[\frac{12}{n(n+1)} \sum_{j=1}^c \frac{T_j^2}{n_j} \right] - 3(n+1),$$

where n is the sum of sample sizes for all groups, c is the count of groups, T_j is the sum of ranks in j -th group and n_j is the size of the j -th group. The authors opted for post-hoc testing in order to determine specific differences between individual groups. The Dwass–Steel–Critchlow–Fligner (DSCF) test is a nonparametric post-hoc procedure used to compare all possible pairs

of groups after a significant Kruskal–Wallis test, see (Anděl, 2005; Hendl, 2006).

The calculations were performed with the help of the UNISTAT, SPSS, Statistica, and Jamovi software, like the authors (Smoluk-Sikorska et al., 2020; Rojík et al., 2022; Zámková et al., 2020, 2022, 2024). The results of this research may serve as a way to define and refine the target groups and to create the target consumer group’s profile.

The statistical methods described above were used to test hypotheses based on the research questions outlined in Chapter 1.5. Logistic regression was used to determine the relationship between awareness of Czech and European organic product labelling and selected sociodemographic indicators. The evaluation of the attributes that consumers most frequently associate with organic products labeled with both Czech and European labels was conducted using contingency table analysis and correspondence analysis. At the same time, nonparametric analysis of variance (Kruskal–Wallis test and post-hoc testing) was used to determine how this perception differs among respondents based on age, gender, and education.

3 RESULTS

This study aims to compare the recognition of labelling systems and analyses the associations consumers in the Czech Republic make with

regard to the labels on organic products on both national and European level and their dependence on selected socio-demographic indi-

cators. First of all, the overall dependence was examined, which means all selected parameters were considered, using logistic regression. The recognition of the labelling system was coded as 1 (yes) and 0 (no). The rising values of socio-demographic indicators were defined on an increasing scale of 0, 1, 2, ..., with the exception of gender, which was coded as 1 (male) and 0 (female).

The results of the logistic regression for the Czech labelling system “biozebra” are listed in Tab. 2a and Tab. 2b, which includes the values of regression coefficient, standard error, the value of the Wald statistics, the *p*-value of each regression coefficient, and the confidence interval for the value of regression coefficient.

Based on the results of the logistic regression, see Tab. 2a, it is clear that the recognition of the Czech “biozebra” system is only insignificantly depending on the selected identification questions. However, there is a significant dependence on the age of the respondents. The

signs of regression coefficients indicate that the recognition of this labelling system decreases with the increasing age of respondents. The dependence on other parameters was not statistically significant, however the signs of regression coefficients clearly imply that women are somewhat more familiar with the “biozebra” label than men. The recognition of the label increases with higher education as well. The results of the logistic regression after removing the non-significant variables are presented in Tab. 2b.

As for the European labelling system, based on the results of the logistic regression, see Tab. 3a and Tab. 3b, it is clear that the recognition of the European system is again only insignificantly depending on the selected identification questions. The dependence on the respondents’ education shows borderline values. According to the signs of regression coefficients it may be argued that the recognition of the European organic produce labelling system increases with education. The dependence on

Tab. 2: Regression model parameters – Czech organic food labelling
Part a)

Logistic regression	Coefficient	Standard Error	Wald Statistic	Significance	Lower 95%	Upper 95%
Constant	1.70	0.23	54.74	0.00	1.25	2.15
Gender	−0.03	0.17	0.03	0.86	−0.36	0.30
Age	−0.16	0.08	4.46	0.03	−0.31	−0.01
Education	0.09	0.09	1.01	0.31	−0.08	0.25

Part b) after removing the non-significant variables

Logistic regression	Coefficient	Standard Error	Wald Statistic	Significance	Lower 95%	Upper 95%
Constant	1.84	0.14	152.02	0.00	1.54	2.13
Age	−0.17	0.08	4.85	0.03	−0.32	−0.02

Tab. 3: Regression model parameters – European organic food labelling
Part a)

Logistic regression	Coefficient	Standard Error	Wald Statistic	Significance	Lower 95%	Upper 95%
Constant	0.27	0.17	2.53	0.11	−0.06	0.61
Gender	−0.22	0.13	2.89	0.09	−0.48	0.03
Age	−0.01	0.06	0.03	0.86	−0.13	0.11
Education	0.13	0.07	3.71	0.05	−0.00	0.25

Part b) after removing the non-significant variables

Logistic regression	Coefficient	Standard Error	Wald Statistic	Significance	Lower 95%	Upper 95%
Constant	0.14	0.12	1.19	0.28	−0.11	0.38
Education	0.13	0.06	3.96	0.05	0.00	0.26

other parameters was not statistically significant, however the signs of regression coefficients clearly imply that women are more familiar with the European label than men. The results of the logistic regression after removing the non-significant variables are presented in Tab. 3b.

Tab. 4: Organic food labelling

Organic food labelling	Czech	European
Higher quality, Health	24.2%	17.7%
Luxury, Prestige	6.0%	7.2%
Ecology, Environmental friendliness	34.3%	19.5%
Supporting domestic, producers	9.5%	4.5%
Higher price	8.9%	9.8%
I don't know this brand	17.1%	41.3%

Overall, consumers tend to associate the Czech “Product of organic farming” label (so called “biozebra”) most often with ecology and environmental friendliness. The respondents also seemed to associate these labels with higher product quality while they also perceived the food in question as healthier, see Tab. 4. The European label was most often associated with ecology and environmental friendliness, higher quality, and was perceived as healthier. Consumers proved to be much less familiar with the European labelling system than with the national “biozebra” label, see Fig. 1.

The development of the dependencies may be observed in greater detail thanks to the contingency tables’ and correspondence maps’ analysis. There are no significant differences in the perception of the “biozebra” label when it comes to respondents and their gender. A significantly larger number of women perceive the European labelling as ecological and environmentally friendly. Women have better knowledge of both labelling systems, see Tab. 5.

The least impressed by supposed higher quality of products labelled as “biozebra” seems to be Generation X. Generation Z on the other hand are most skeptical about the quality and health benefits of the European label. When it comes to ecology and environmental friendliness, Generation X seems to be the most in favor of the “biozebra” label. Generation Z are the strongest believers in the eco-nature of the European label. The respondents do not overly associate any of the labelling systems with any support towards domestic producers. However, when it comes to the Czech label, this perception is twice as high compared to the European system. The higher the age of respondents, the higher their acceptance of the “biozebra” products’ price. Younger respondents (Generation Z) clearly do not perceive these foods as expensive (see values for European labelling system). Members of

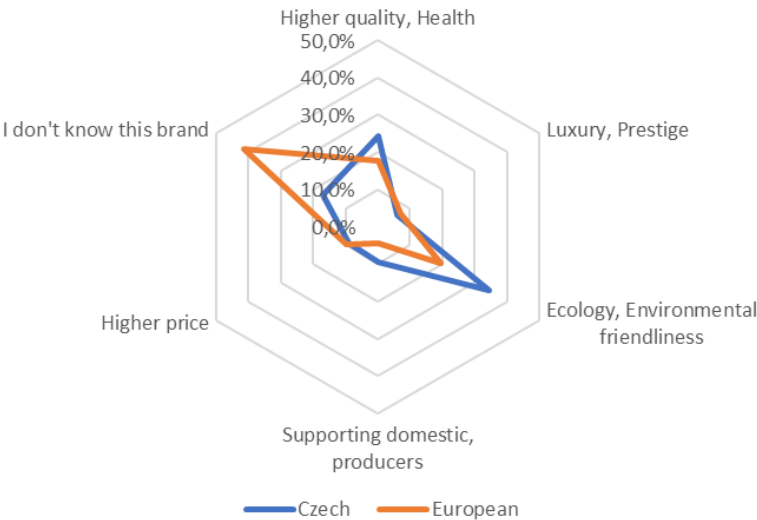


Fig. 1: Czech and European organic food labelling

Generations X and Y are the ones most familiar with the European labelling-system for organic food. The “biozebra” label is most recognized by consumers from Generation Z. In their case, there is a statistically significant dependence (p -value = 0.01).

As shown in the correspondence map, Generation X in most cases agree that the “biozebra” label supports local producers. Baby boomers are the ones least familiar with this label and most likely to associate it with higher price, see Fig. 2.

As for the European label for organic food, Baby boomers are most likely to associate it with higher quality. Additionally, Generation Z often perceives the European label as ecological, see Fig. 3.

The perception of both labelling-systems as proofs of quality and healthy products increases with the education of respondents, see Tab. 8 and Tab. 9. Conversely, the perception that any of these labels could signify luxury or prestige tend to decrease with higher education. Mainly consumers with higher education tend to associate both labels with ecological and environmentally friendly products. Respondents with lower education are the most likely to associate European labels with the support towards local producers. The higher the education of respondents, the less likely they are to associate the “biozebra” label with higher price. Respondents with finished secondary education and a diploma are the most likely to associate products with European labels with higher prices. The recognition of both labelling

Tab. 5: Organic food labelling & Sex

Organic food labelling	Czech		European	
	Men	Women	Men	Women
Higher quality, Health	24.12%	24.36%	18.68%	16.67%
Luxury, Prestige	6.81%	5.13%	6.61%	7.91%
Ecology, Environmental friendliness	33.07%	35.68%	17.12%	22.01%
Supporting domestic, producers	9.92%	8.97%	4.86%	4.06%
Higher price	8.75%	8.97%	8.75%	10.90%
I don't know this brand	17.32%	16.88%	43.97%	38.46%

Tab. 6: Czech organic food labelling

Organic food labelling	Gen Z	Gen Y	Gen X	Baby boomers
Higher quality, Health	27.95%	23.83%	20.41%	24.67%
Luxury, Prestige	5.91%	8.20%	4.49%	5.29%
Ecology, Environmental friendliness	35.83%	33.98%	40.82%	25.99%
Supporting domestic, producers	10.63%	6.64%	11.43%	9.25%
Higher price	6.69%	8.20%	8.98%	11.89%
I don't know this brand	12.99%	19.14%	13.88%	22.91%

Tab. 7: European organic food labelling

Organic food labelling	Gen Z	Gen Y	Gen X	Baby boomers
Higher quality, Health	14.96%	18.75%	17.96%	19.38%
Luxury, Prestige	7.09%	8.20%	8.57%	4.85%
Ecology, Environmental friendliness	22.83%	18.75%	17.55%	18.50%
Supporting domestic, producers	3.15%	6.25%	6.12%	2.20%
Higher price	7.48%	11.33%	10.61%	9.69%
I don't know this brand	44.49%	36.72%	39.18%	45.37%

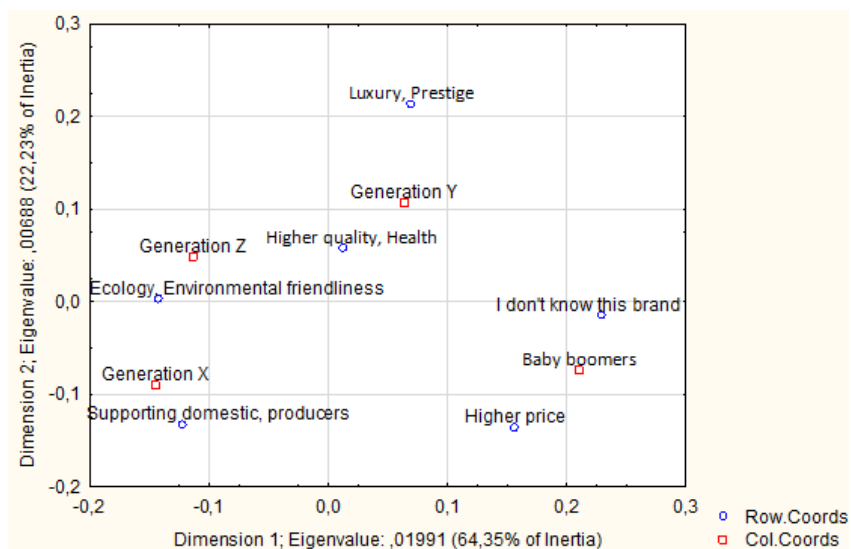


Fig. 2: Czech organic food labelling & Age

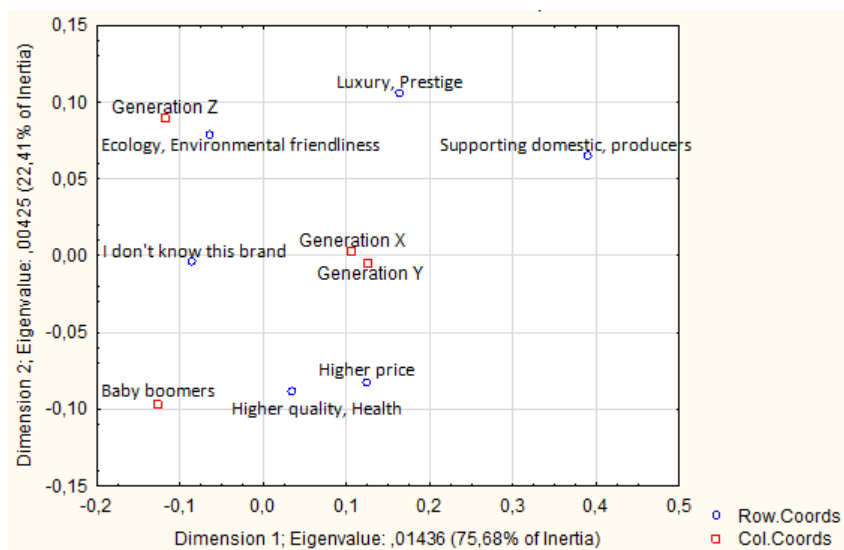


Fig. 3: European organic food labelling & Age

Tab. 8: Czech organic food labelling & Education

Organic food labelling	Primary	Secondary	Secondary with high school diploma	Tertiary
Higher quality, Health	20.69%	24.64%	24.53%	25.52%
Luxury, Prestige	9.66%	7.25%	5.28%	3.35%
Ecology, Environmental friendliness	27.59%	30.43%	36.96%	39.33%
Supporting domestic, producers	8.97%	8.70%	10.56%	9.21%
Higher price	12.41%	11.59%	6.52%	6.69%
I don't know this brand	20.69%	17.39%	16.15%	15.90%

Tab. 9: European organic food labelling & Education

Organic food labelling	Primary	Secondary	Secondary with high school diploma	Tertiary
Higher quality, Health	10.34%	19.93%	20.19%	16.32%
Luxury, Prestige	10.34%	6.88%	8.07%	4.60%
Ecology, Environmental friendliness	13.10%	18.84%	18.32%	25.52%
Supporting domestic, producers	7.59%	2.90%	3.73%	5.44%
Higher price	8.28%	8.70%	13.35%	7.11%
I don't know this brand	50.34%	42.75%	36.34%	41.00%

systems increases with the education of respondents. Here as well was found a statistically significant dependence (p -value = 0.01).

The correspondence map clearly illustrates that respondents with elementary education are the most likely to associate Czech labelling with luxury and prestige. Respondents with a university degree tend to consider these products to be of higher quality, healthier and eco-friendly, see Fig. 4.

Respondents from both categories of secondary education tend to associate the European label with higher quality of products most often. Similarly, to the Czech label, the European logo is often perceived as a sign of ecology by respondents with tertiary education, see Fig. 5.

Additionally, in order to compare the results between different citizen groups, the authors employed non-parametric analysis of variance. A decreasing scale was used in order to differentiate the intensity of perception (1 = strongly agree; 7 = strongly disagree). The results of the non-parametric analysis of variance indicate that based on gender, there are no significant differences between individual citizen groups, see Tab. 10.

The results of the non-parametric analysis of variance indicate that as for age, there are no significant differences between individual citizen groups, see Tab. 11.

The results of the non-parametric analysis of variance indicate that when it comes to education, there are significant differences between individual citizen groups only in the case of price perception (eco-labels are perceived as more expensive compared to normal food) and another difference is in the perceived support

of local producers and their eco-friendliness, see Tab. 12.

Tab. 10: Kruskal–Wallis test – Sex

	<i>H</i>	<i>df</i>	<i>p</i>
Higher quality, Health	2.52	1	0.113
Luxury, Prestige	0.09	1	0.768
Ecology, Environmental friendliness	0.33	1	0.567
Supporting domestic, producers	1.08	1	0.298
Higher price	0.52	1	0.471

Tab. 11: Kruskal–Wallis test – Age

	<i>H</i>	<i>df</i>	<i>p</i>
Higher quality, Health	5.49	3	0.139
Luxury, Prestige	1.73	3	0.631
Ecology, Environmental friendliness	0.31	3	0.958
Supporting domestic, producers	5.25	3	0.154
Higher price	3.71	3	0.295

Tab. 12: Kruskal–Wallis test – Education

	<i>H</i>	<i>df</i>	<i>p</i>
Higher quality, Health	7.35	3	0.062
Luxury, Prestige	1.20	3	0.753
Ecology, Environmental friendliness	9.40	3	0.024
Supporting domestic, producers	10.75	3	0.013
Higher price	14.84	3	0.002

Tab. 13a and Tab. 14 is a clear demonstration of the fact that the post-hoc analysis proved significant difference in the perception of products with eco-labels as more expensive by respondents with elementary, secondary (with diploma), and tertiary education. Respondents

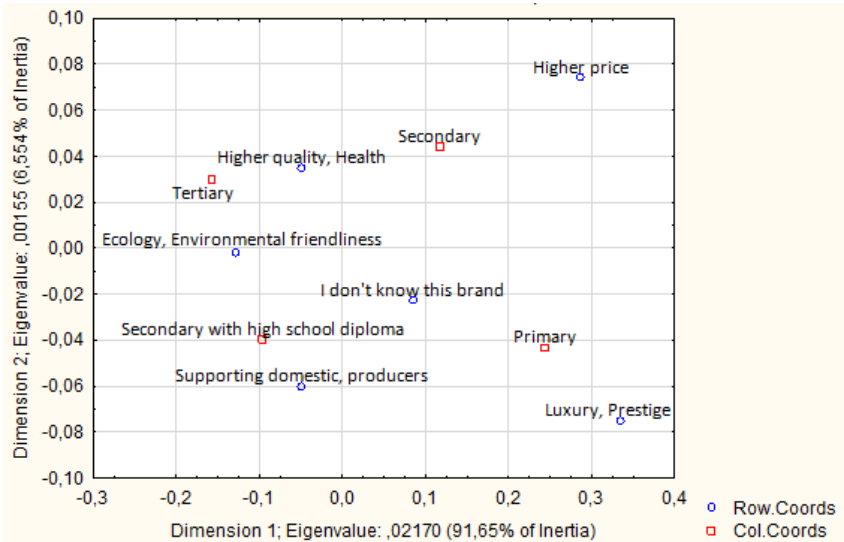


Fig. 4: Czech organic food labelling & Education

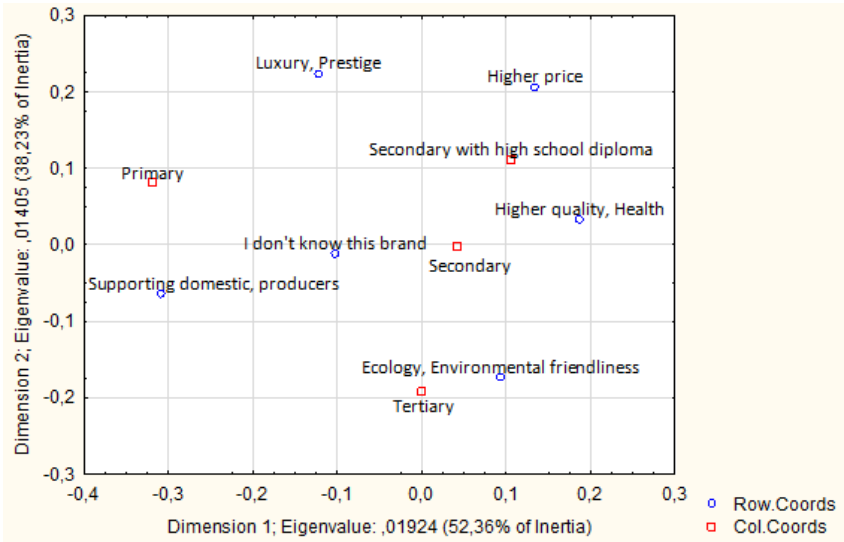


Fig. 5: European organic food labelling & Education

with elementary education are significantly more likely to perceive the products as more expensive.

As shown in Tab. 13b and Tab. 14, the post-hoc analysis revealed a significant difference in the perceived support towards local producers of both of these eco-labels when comparing the respondents with elementary education and

secondary education (diploma). Respondents with elementary education are significantly less likely to perceive these products as helpful for local producers. Tab. 13c depicts the results of the post-hoc analysis focusing on perceived ecological and environmentally friendly nature of these labelling-systems.

Tab. 13: Pairwise comparisons – a) Education × Higher price; b) Education × Supporting domestic, producers; c) Education × Ecology, Environmental friendliness (A = Primary; B = Secondary; C = Secondary with high school diploma; D = Tertiary)

	a) Education × Higher price		b) Education × Supporting domestic, producers		c) Education × Ecology, Environmental friendliness	
	<i>W</i>	<i>p</i>	<i>W</i>	<i>p</i>	<i>W</i>	<i>p</i>
D B	−2.99	0.150	1.33	0.784	2.94	0.160
D C	0.07	1.000	−1.45	0.733	−0.34	0.995
D A	−4.56	0.007	2.93	0.161	2.47	0.299
B C	2.98	0.151	−2.98	0.151	−3.53	0.061
B A	−1.95	0.514	1.97	0.502	−0.07	1.000
C A	−4.56	0.007	4.33	0.012	2.98	0.151

Tab. 14: Kruskal–Wallis test – Mean Rank (A = Primary; B = Secondary; C = Secondary with high school diploma; D = Tertiary)

	A	B	C	D
Higher price	428.09	468.85	518.61	519.61
Supporting domestic, producers	545.04	506.80	459.80	484.06
Ecology, Environmental friendliness	522.47	522.58	465.67	471.61

4 DISCUSSION

The results of this study provide important insights into the perception and knowledge of organic product labels among Czech consumers. As the analysis has shown, the familiarity with the Czech organic label “biozebra” and the European organic label varies significantly across different demographic groups, highlighting key factors that influence consumer behavior in the context of organic food consumption. One of the main findings is that knowledge of the Czech national label “biozebra” decreases with age, suggesting that younger consumers are more familiar with this national certification. This trend may be attributed to the increasing environmental awareness among younger generations, which aligns with findings from studies by Kareklas et al. (2014) and Yadav (2016), who identified ecological concern as a primary motivator for purchasing organic products. On the other hand, the relatively higher recognition of the European organic label among more educated consumers suggests a correlation between education and the likelihood of being informed about international certifications, as noted in the literature on food labelling (Jürkenbeck, 2023; Grunert and Aachmann, 2016).

The association of both labels with higher quality and health benefits among consumers is consistent with previous research that suggests consumers perceive organic products as superior in quality and more beneficial for health (Magnusson et al., 2003; Smith-Spangler et al., 2012). However, it is noteworthy that while these associations are strong, a significant portion of the population remains unaware of the European label, indicating a potential gap in consumer education or marketing efforts regarding this certification. This finding underscores the need for targeted communication strategies, particularly towards less informed demographics, as suggested by Grunert et al. (2014). Additionally, the higher association of organic labels with environmental friendliness among women aligns with global trends indicating that women are generally more concerned about ecological issues (McCarthy et al., 2016). This gender difference in the perception of organic labels may provide valuable guidance for marketers aiming to strengthen the appeal of organic products among male consumers.

The study also reveals that price sensitivity continues to be a barrier to the wider adoption of organic products, despite the perceived benefits. This is particularly evident among consumers with lower educational levels, who are more likely to associate organic products with luxury and higher costs. This observation resonates with the findings of Hughner et al. (2007) and Bezawada and Pauwels (2013), who emphasized that while price remains a significant factor, the perceived health and environmental benefits can justify the premium for certain consumer segments.

5 CONCLUSIONS

As part of the research question regarding the attributes with which consumers most often associate organic products labeled with both Czech and European labelling, it was found that products labelled with the Czech logo are most often associated with ecology and environmental friendliness. The respondents also seem to associate these labels with higher product quality while they perceive the food in question as healthier too. The European label tends to be most often associated with ecology and environmental friendliness, higher quality, and is also perceived as healthier. Czech consumers proved to be much less familiar with the European labelling system than with the national “biozebra” logo.

As part of the research question regarding knowledge of Czech and European labelling of organic products this study furthermore focused on the perception of these labelling systems and its dependence on selected socio-demographic indicators. There are no significant differences in the perception of the “biozebra” label when it comes to respondents and their gender. A significantly larger number of women perceive the European labelling as ecological and environmentally friendly. Both labelling systems are more often recognized by women.

Regarding the research question examining perceptions of how perceptions of attributes differ among respondents based on age, gender, and education, it was found that the least im-

Finally, the lack of strong associations between organic labels and the support for domestic producers indicates an area where both national and European labels could enhance their appeal. As local production becomes increasingly valued in the context of sustainability, emphasizing the connection between organic certification and local economic support could strengthen consumer loyalty, particularly among older generations and those with higher educational levels (Garnier and Bilen, 2025; Pino et al., 2012).

pressed by supposed higher quality of products labelled as “biozebra” seems to be Generation X. Generation Z on the other hand is most skeptical about the associated quality and health benefits. When it comes to ecology and environmental friendliness, Generation X seems to be the most in favor of the “biozebra” label. Conversely, Generation Z are the strongest believers in the eco-nature of the European label. Consumers are not likely to associate any of the labelling systems with any support that would be going towards local producers, only the correspondence map shows that Generation X most strongly agrees that the “biozebra” label constitutes a sign of any such support. Still, when it comes to the Czech label, this perception (as being supportive towards local producers) is twice as high compared to the European system. The higher the age of respondents, the higher their acceptance of the “biozebra” products’ price. Baby boomers are the ones least familiar with this label and most likely to associate it with higher price. Younger respondents (Generation Z) clearly do not perceive foods with the European logo as expensive. Baby boomers are most likely to associate it with higher quality. Members of Generations X and Y are the ones most familiar with the European labelling-system for organic food. The “biozebra” label is most recognized by consumers from Generation Z.

The perception of both labelling-systems as proofs of quality and healthy products

increases with the education of respondents. Respondents from both categories of secondary education tend to associate the European label with higher quality of products most often. Conversely, the perception that any of these labels could signify luxury or prestige tends to decrease with higher education. Mainly consumers with higher education tend to associate both labels with ecological and environmentally friendly products. The higher the education of respondents, the less likely they are to associate the “biozebra” label with higher price. The post-hoc testing revealed the following results: Respondents with elementary education are significantly more likely to perceive both labelling systems as such (expensive) than respondents with the highest education; There is a significant difference in the perceived support towards local producers of both of these eco-labels when comparing the respondents with elementary education and secondary education (diploma). Respondents with elementary education are significantly less likely to perceive these products

as helpful for local producers. The recognition of both labelling systems increases with the education of respondents.

The results of the research showed that the Ministry of Agriculture of the Czech Republic, as the coordinator and guarantor of organic/bio product labelling, should focus its communication campaign to promote organic products on the communication of these products in relation to ecology, especially to the youngest age group, and to consumers with secondary and higher education, who are the most prospective customer group for these products. In conclusion, the findings also suggest that for the Ministry of Agriculture in the Czech Republic, the focus of promotional campaigns should be on enhancing awareness and knowledge of both national and European organic labels, particularly emphasizing their environmental benefits. Such efforts should be tailored to resonate with younger consumers and those with higher education, who represent the most promising market segments for organic products.

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