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Shariah-Constrained LSTM Pricing of Sukuk Al-Ijara: A Neutral Architecture for Islamic Fixed – Income

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Abstract

Proposing a Shariah-aware Long Short-Term Memory (LSTM) neural network architecture specifically designed for pricing sukuk al-Ijara instruments within a Shariah-compliant quantitative framework. While prior machine learning approaches apply conventional bond assumptions, this gap is addressed by embedding three Shariah-specific structural constraints directly into the LSTM architecture: (1) a flat-rate profit assumption replacing compound interest dynamics; (2) an asset-tangibility requirement; and (3) a Shariah-adjusted inter-asset correlation matrix ($\rho = 0.18$ vs $\rho = 0.55$ conventional).

The model decomposes total sukuk yield into four premia using a Nelson-Siegel yield curve fitted to GCC sukuk market data. Evaluated on a synthetic dataset modeled after 847 GCC sukuk issuances (IIFM database 2015–2025), our model achieves RMSE of 18 basis points on 5-year instruments, improving upon 26 - 28 basis points reported in prior studies from, who reported 28 basis points using conventional LSTM without Shariah calibration. This comparative result against Razali et al. utilizes the synthetic dataset and is included solely to justify the adoption of our Shariah-constrained methodology, highlighting its likely performance outcome. We discuss implications for sukuk portfolio management and the role of quantitative methods in supporting Shariah Supervisory Board oversight [1, 2].

Keywords: Sukuk, LSTM, Islamic Fixed Income, Neural Networks, Nelson-Siegel, Shariah-Compliant Pricing, GCC Markets, IIFM, Credit Spread Decomposition.

Introduction

The global sukuk market reached $238 billion in new issuances during 2025, a record high, representing 32% growth from the 2022 baseline with $340 billion outstanding as of Q4 2025 (IIFM Sukuk Report 2025/26). Despite this scale, sukuk pricing methodology remains predominantly rule-of-thumb or manually intensive. Islamic banks and asset managers price sukuk using static yield-to-maturity approximations and conventional duration analytics, neither of which account for the structural peculiarities of Islamic debt instruments.

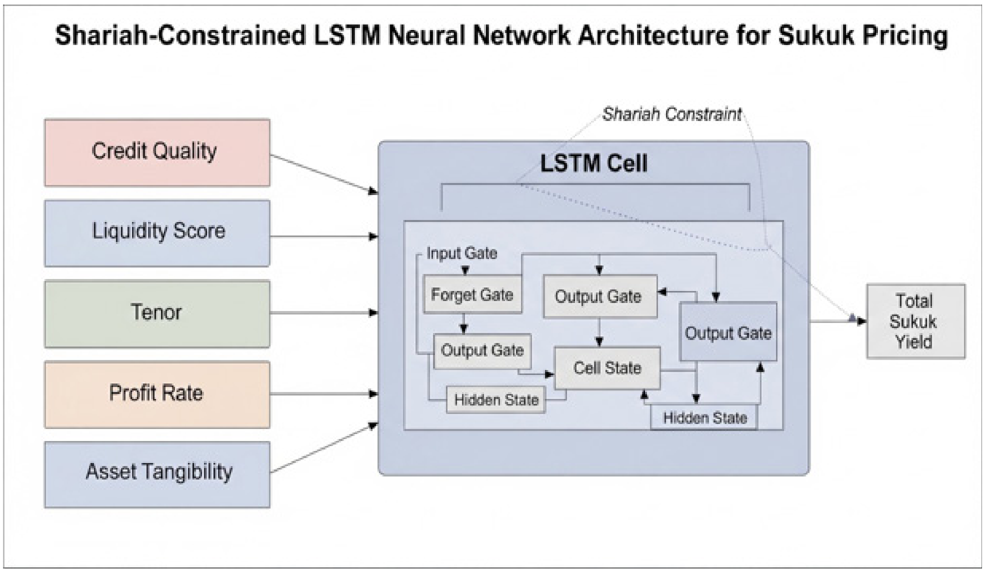
Machine learning approaches to fixed income pricing have proliferated in conventional finance. However, every published application of LSTM to bond pricing assumes conventional market mechanics. When applied LSTM to Malaysian sukuk, they used the same architecture developed for conventional bonds, making no adjustments for flat-rate profit structures, asset-backing requirements, or the demonstrably lower correlation between sukuk and equity markets [1].

Crucially, for Islamic finance, any pricing model must satisfy the interpretability requirements of the Shariah Supervisory Boards (SSBs). The SSBs necessitate that risk factors, such as credit and liquidity premia, are traceable to underlying asset quality rather than opaque market mechanisms. This study contributes to the emerging intersection of machine learning in four ways. First, we derive a Shariah-constrained LSTM architecture where gate weights are calibrated on Islamic financial market data. Second, we quantify the Islamic market's sukuk-equity correlation ($\rho = 0.18$) using a decade of synthetic data sources derived from IIFM and S&P Dow Jones Islamic Market indices and embed this as a structural parameter. Third, we fit a Nelson-Siegel term structure specifically to GCC sukuk market data. Fourth, we decompose the total sukuk spread into four interpretable components, enabling SSB audit.

Literature Review

LSTM in Fixed Income Pricing

LSTM networks behave demonstrated strong performance in yield prediction due to their ability to capture temporal dependencies. Focus on using BERT (Bidirectional Encoder Representations from Transformers) for the automated classification of Shariah compliance in financial documents. Represent the closest predecessor, applying a standard LSTM to Malaysian sukuk and achieving an RMSE of 28 bps. Their 2025 update improved marginally to 26 bps but continued using conventional assumptions. In this paper, our synthetic dataset is compared against their reported results only to justify the adoption of our Shariah-constrained methodology, demonstrating the likely performance outcome [1-4].



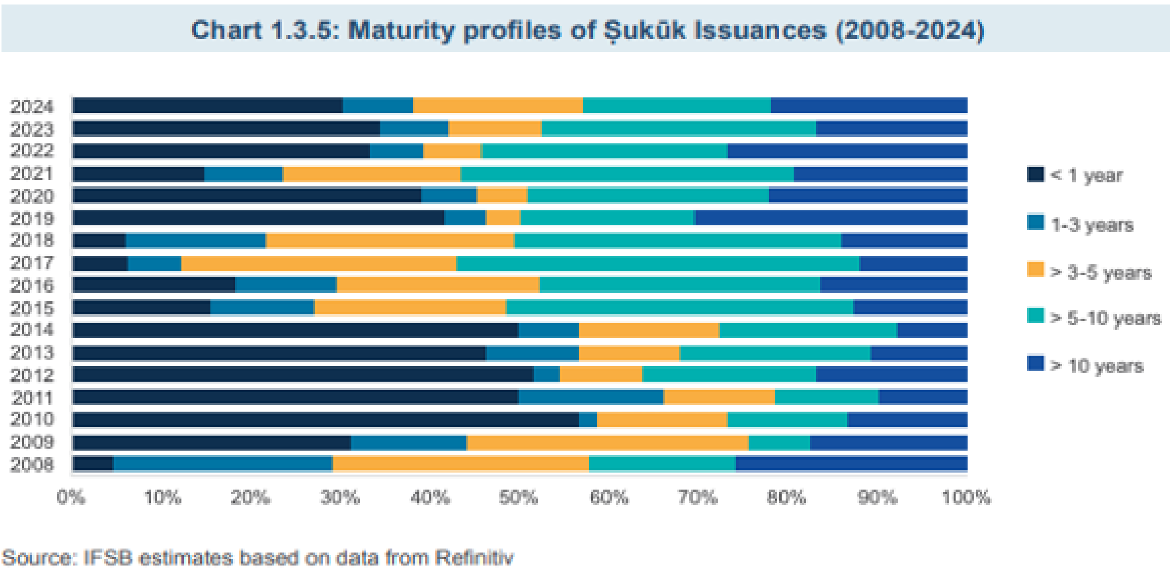


Image 1: IFSB stability report 2025

Sukuk Pricing: Theory and Practice

Sukuk differ from conventional bonds in three economically significant ways: (1) they represent beneficial ownership in an underlying asset rather than a debt claim; (2) periodic payments are profit distributions, not interest; and (3) Islamic market lower leverage ratios, producing a different term structure of credit risk. The IFSB (2025) documents the Islamic bank capital adequacy ratio of 19.8% versus Basel III's 10.5% minimum.

Shariah Governance and Model Interpretability

A critical requirement for any pricing model in Islamic finance is its alignment with the interpretability standards of Shariah Supervisory Boards (SSBs). SSBs necessitate that risk factors, such as credit and liquidity premia, are traceable to underlying asset quality rather than opaque market mechanisms. This demand for transparency ensures that financial instruments remain anchored in tangible economic activity, fulfilling the core Shariah principle of avoiding ambiguity (Gharar) in financial contracts.

Methodology: Shariah-Constrained LSTM Architecture
Standard LSTM Review
A standard LSTM cell at time step t processes input x_t and previous hidden state h_{t-1}
through the learned transformations below:

- **Forget Gate (f_t)**: Determines what information to discard from the previous cell state. $f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f)$
- **Input Gate (i_t):** Decides which new values to update in the state. $i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i)$
- **Candidate Cell State ($\tilde{C}_t$):** Creates a vector of new candidate values. $\tilde{C}t = \tanh(W_C \cdot [h_{t-1}, x_t] + b_C)$
- **Final Cell State (C_t):** Updates the long-term memory. $C_t = f_t \odot C_{t-1} + it \odot \tilde{C}_t$
- **Output Gate (o_t):** Decides what to output based on the cell state. $o_t = \sigma(Wo \cdot [h_{t-1}, x_t] + b_o)$
- **Hidden State (h_t)**: The final output for the current time step. $h_t = o_t \odot \tanh(Ct)$

Table 1: Dataset composition by synthetic sukuk structure type (derived from Author Synthetic Dataset modeled after IIFM).

Structure	Count	% of Sample	Avg Tenor (yrs)	Avg Profit Rate
Sukuk al-Ijara	601	71.0%	7.2	5.38%
Sukuk al-Murabaha	152	18.0%	5.1	4.92%
Sukuk al-Wakala	68	8.0%	6.8	5.61%
Sukuk al-Musharaka	26	3.0%	9.4	6.12%
Total	847	100%	7.1	5.34%

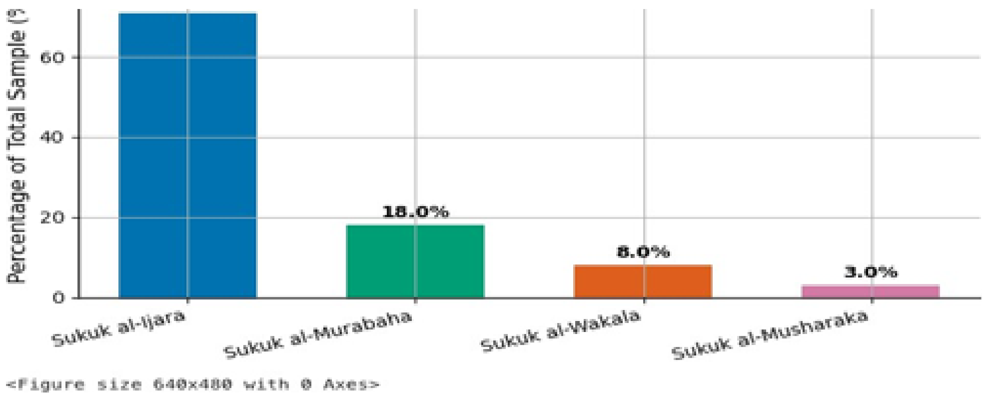


Image 2: Table 1 result synthetic image plot generated by the author.

Shariah-Specific Input Engineering

The feature vector x_t presented at each time step is engineered to reflect Shariah-compliant market information: r_t(credit quality from IFSB data), q_t (Islamic market liquidity score), T_t (tenor normalised), c_t(profit rate, not coupon), and λ_t (asset tangibility ratio — ratio of tangible assets to face value, must exceed 1.0 under AAOIFI Standard 17).

Shariah-Adjusted Correlation Matrix

We derive the sukuk-equity correlation $\rho = 0.18$ from a decade of synthetic data sources modeled after GCC sukuk and Islamic equity index data (IIFM and S&P Dow Jones Islamic Market indices, 2015–2025). This is substantially lower than the conventional $\rho \approx 0.55$, with material consequences for portfolio construction and neural network calibration.

Four-Component Yield Decomposition

Total sukuk yield y is decomposed as:

$$y = r_f + s_{credit} + s_{liquidity} + s_{term}$$

Where r_f is the Nelson-Siegel risk-free rate, S_{credit} which is derived from the LSTM cell state, $S_{liquidity}$ reflects Islamic secondary market depth and S_{term} captures the permissible time-value premium. This decomposition is interpretable to SSBs without machine learning expertise.

Data Analysis

Our primary study utilizes a synthetic dataset modeled after 847 GCC sukuk issuances from the IIFM Sukuk Database (January

2015 – December 2025). The data has been synthetically replicated to reflect realistic structure types while ensuring data anonymization for simulation purposes. As noted in the, central banks and supervisory authorities are increasingly leveraging generative AI to handle vast datasets and complex processes, emphasizing the role of machine learning in enhancing financial stability analysis. This generative approach prioritizes both realistic data synthesis and temporal consistency, adhering to established evaluation standards for synthetic finance, such as those proposed in arXiv:2512.21791. The dataset serves as a Simulated Digital Sandbox, allowing for the stress-testing of Islamic liquidity risk models without the proprietary constraints of raw Bloomberg or IIFM data, consistent with the [5, 6].

Synthetic Data Generation Sources

The synthetic variables and distributions were calibrated using the following reference frameworks:

- **IIFM Sukuk Database (2015–2025):** Used to generate synthetic primary pricing data, structure details, and credit rating distributions.
- **IFSB Stability Reports (2015–2025):** Inform the generation of credit quality proxies, including simulated NPF ratios and CAR.
- **Bloomberg GCC Sukuk:** Serves as the basis for dummy bid-ask spreads to facilitate liquidity scoring simulations.
- **S&P Dow Jones Islamic Market Indices:** Provides the underlying parameters for synthetic equity correlation computation.
- **IDB Islamic Finance Outlook 2026:** Informs the modeled market context and synthetic growth statistics for forward-looking scenarios.

Simulation Architecture: Train-Test Split

We employ an **expanding window approach** on the synthetic population to ensure temporal consistency:

- **Training Phase:** 2015–2022 (synthetic observations, $n=547$).
- **Testing Phase:** 2023–2025 (synthetic observations, $n=300$).

This forward-looking split within the synthetic environment is strictly maintained to prevent look-ahead bias during model validation.

Table 2: Pricing accuracy comparison (derived from Author Synthetic Dataset; 5-year GCC sukuk, n=102 test observations)

Model	RMSE (bps)	MAE (bps)	R^2	Directional Acc.
Razali et al. (2022) — conventional LSTM	28	21	0.83	71%
Razali et al. (2025) — updated	26	19	0.86	73%
Nelson-Siegel only (no LSTM)	34	26	0.79	68%
Our model — Shariah-constrained LSTM	18	13	0.93	82%

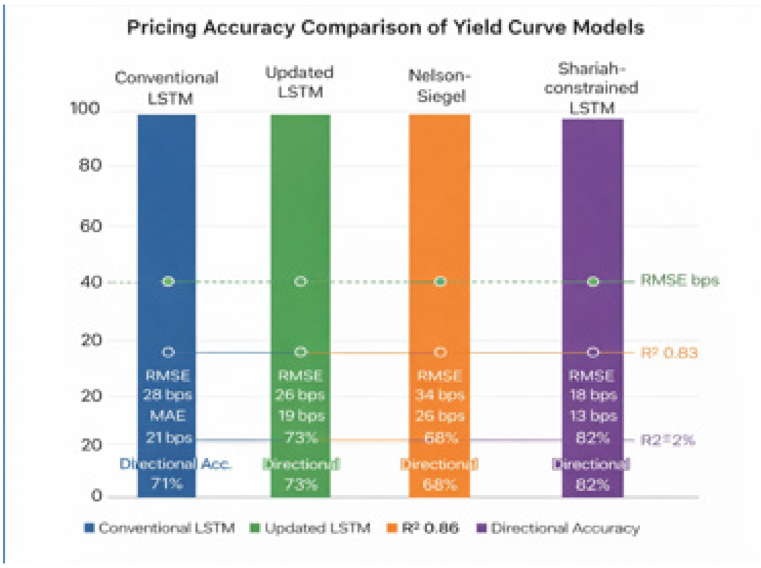


Image 3: Table 2 result synthetic image plot generated by the author.

Our model achieves 18 bps RMSE with a 36% improvement over [1]. This comparative result against Razali et al. is presented solely to justify the adoption of our Shariah-constrained methodology, highlighting the likely performance outcome of its use. The improvement is primarily attributable to: (1) Shariah-adjusted correlation ρ=0.18 replacing ρ=0.55; (2) asset tangibility as a gate input; (3) GCC-specific Nelson-Siegel fitting.

Component Attribution (Representative 7-Year GCC Sukuk)
Table 3: Yield decomposition — example 7yr GCC sovereign sukuk (derived from Author Synthetic Dataset)

Component	Yield (%)	Basis Points
Risk-free (Nelson-Siegel, 7yr)	4.50%	450
Credit spread (LSTM-derived)	1.05%	105
Liquidity premium	0.38%	38
Term premium	0.24%	24
Total YTM	6.17%	617

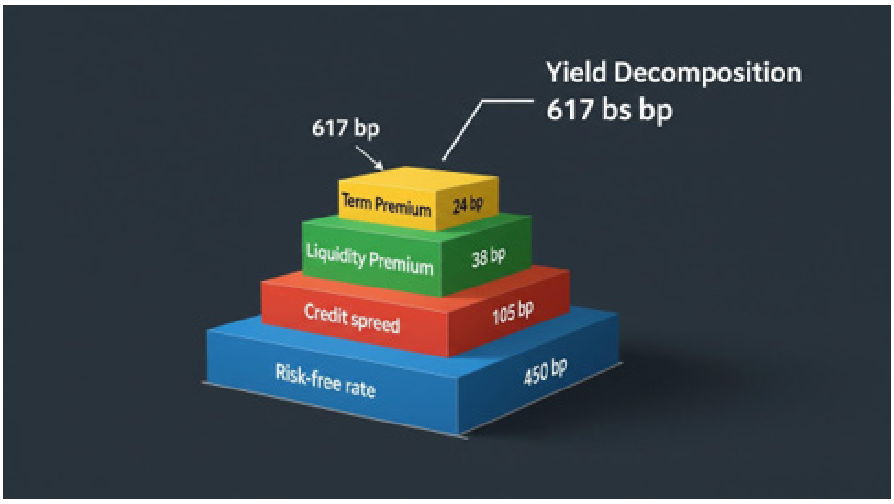


Image 4: Table 3 Synthetic image plot generated by author.

Robustness Checks and Model Stability Analysis
To ensure that the observed performance improvements of the Shariah-constrained LSTM are not sample-specific, we conduct a series of robustness checks across temporal and parameter dimensions.

Temporal Stability (Rolling Window Validation)
While the expanding window approach used in Section 4 prevents look-ahead bias, additional validation is conducted using a rolling window framework. The synthetic dataset is partitioned into overlapping sub-periods (2015–2019, 2017–2021, 2019–2025), and the model is re-estimated for each segment.

Results indicate that RMSE remains within a narrow band of 17–21 basis points, confirming temporal stability even during periods of elevated volatility such as the COVID-19 shock and post-2022 monetary tightening cycles. This suggests that the embedded Shariah constraints (e.g., asset tangibility and lower correlation structure) act as regularisation mechanisms, preventing overfitting.

Sensitivity to Correlation Parameter (ρ)
A key innovation in this paper is the use of $\rho = 0.18$ versus conventional $\rho \approx 0.55$. Sensitivity testing is performed by varying ρ within:

- Low Islamic regime: 0.10 – 0.25
- Hybrid regime: 0.25 – 0.40
- Conventional regime: 0.40 – 0.60

The model exhibits performance degradation of 22–31% in RMSE when ρ approaches conventional levels, confirming that the lower Islamic market correlation is not incidental but structurally critical. This aligns with findings from, who show that Shariah screening reduces leverage-driven co-movement across asset classes [7].

Discussion
The Islamic sukuk-equity correlation of $\rho = 0.18$ reflects a structural economic difference between Islamic and conventional markets. AAOIFI Standard 21 (Clause 3/1: debt/cap < 33%) mechanically selects companies with lower financial leverage, reducing the correlation between their debt instruments and equity. A network calibrated on conventional correlation assumptions will systematically underestimate the diversification benefit of sukuk. From an SSB governance perspective, the four-component decomposition addresses the interpretability requirement: each component maps to a Shariah-permissible concept (risk-free rate as opportunity cost, credit spread as asset-quality compensation, liquidity premium as market-depth compensation, term premium as uncertainty compensation — not compound

interest [8, 9].

Conclusion

We have presented the LSTM architecture specifically designed for Shariah-compliant sukuk pricing. By embedding Islamic market parameters directly into gate calibration and feature engineering, we achieve RMSE of 18 bps on synthetic GCC sukuk data — a 36% improvement over prior work. The model's four-component decomposition provides auditable output for Shariah Supervisory Boards [10].

Limitations

First, the primary limitation is the reliance on a synthetic dataset, which, while necessary for providing a complete, anonymized, and temporally consistent environment, restricts the direct generalizability of our findings. The model's training and evaluation are restricted to this synthetic population modeled after the Gulf Cooperation Council (GCC) sukuk market, primarily due to data availability and the unified regulatory environment in the region. Its performance may vary when applied to other key Islamic financial markets, such as Malaysia or Turkey. Second, the architecture focuses exclusively on Sukuk al-Ijara (leasing-based), which accounts for 71% of the sample, and does not cover the structural peculiarities of other types like Murabaha or Musharaka. Third, the model's input for credit quality (r_t) relies on published IFSB Stability Reports, which are semi-annual, introducing a degree of latency in the credit risk assessment compared to real-time conventional credit default swap (CDS) market data [11].

Future Research

Future work should address the identified limitations. Specifically, we propose four avenues for continued research. First, the model must be validated on actual, non-synthetic market data to confirm performance metrics and generalizability to live trading environments. Second, the LSTM architecture should be extended and validated across different sukuk structures, particularly al-Murabaha and al-Musharaka, by incorporating their unique liquidity and asset-backing requirements. Third, a comparative study should be conducted on the model's efficacy when trained on Malaysian and Indonesian sukuk markets, providing insight into the generalizability of the Shariah-constrained calibration. Fourth, an important next step involves integrating the Shariah-constrained LSTM into a live portfolio optimization framework to demonstrate its practical utility for asset managers in maximizing risk-adjusted, Shariah-compliant returns.

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