Hybrid Option Valuation: PINN Models Informed by Black-Scholes and Alternative Data Sources

MICHIGAN ENGINEERING
UNIVERSITY OF MICHIGAN

Kiran Bodipati, Jehan Patel, Dhanush Kumar Mallu

GitHub

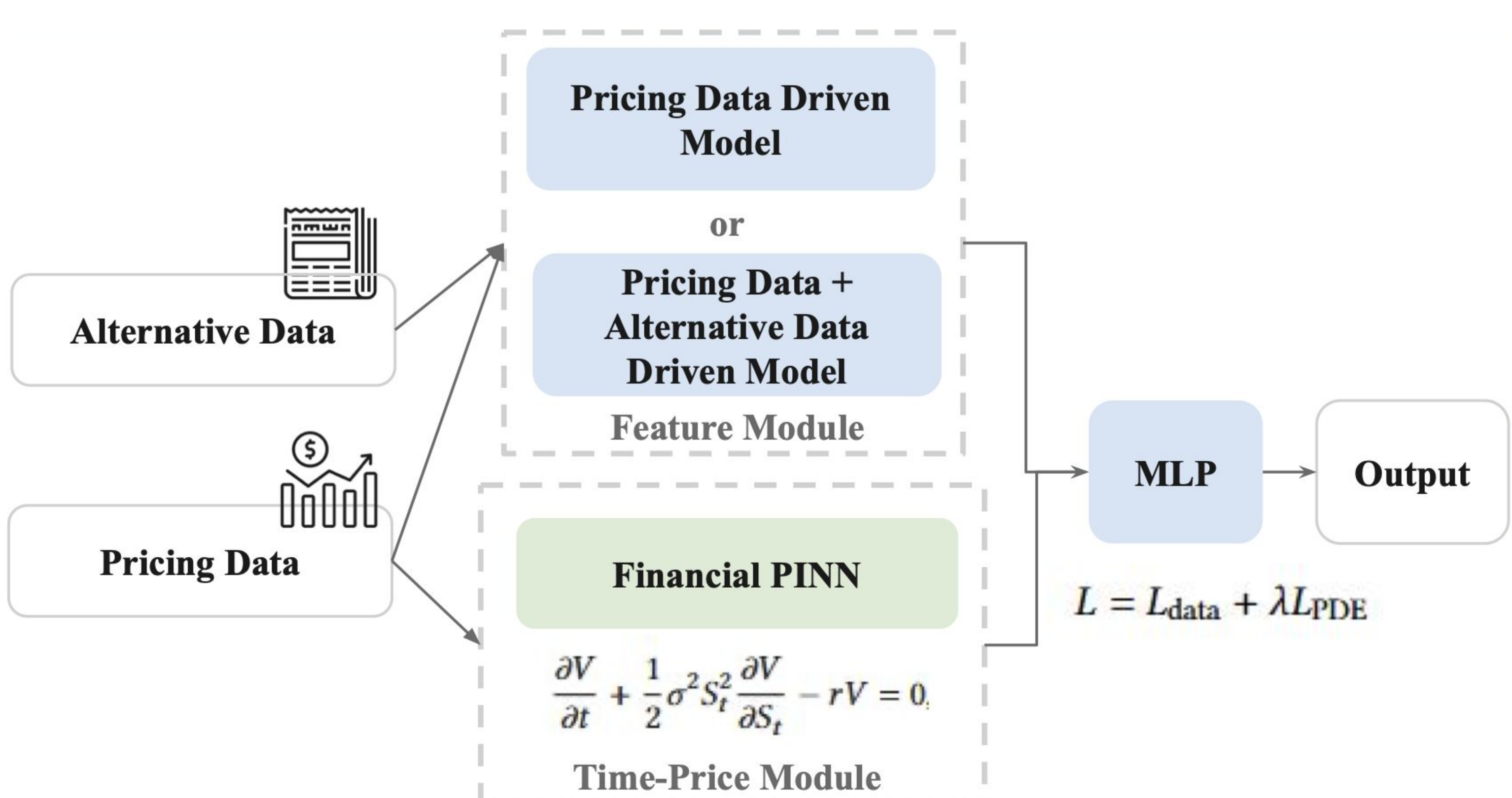
Motivation

Valuation of stock options is critical in finance. However:

- **Traditional Black-Scholes models** only use traditional financial data, missing fast-moving news and sentiment
- **Alternative data sources** (e.g. social media sentiment) are now accessible, but data-driven models overfit these signals

We address this research gap by proposing a hybrid approach: PINNs treat Black-Scholes as a guiding constraint, while deep networks are trained on both traditional and alternative data

Methods



Feature Modules

- **Physics-Informed Neural Network (PINN):** Enforces Black-Scholes as soft constraint on loss function, combining pure financial theory and empirical data
- **Pure Data-Driven Module:** Trained MLPs, LSTMs, GRUs
- **Pure Black-Scholes Module:** Classic theoretical pricing

Transfer Learning Approach

- Combines representations learned from financial theory (PINN) with those from data-driven models
- Uses shared loss function and gradient matching to guide feature modules with theoretical constraints

Data

Traditional Data: Daily S&P 500 close prices, volumes, volatility, strike prices, expiration dates

Alternative Data

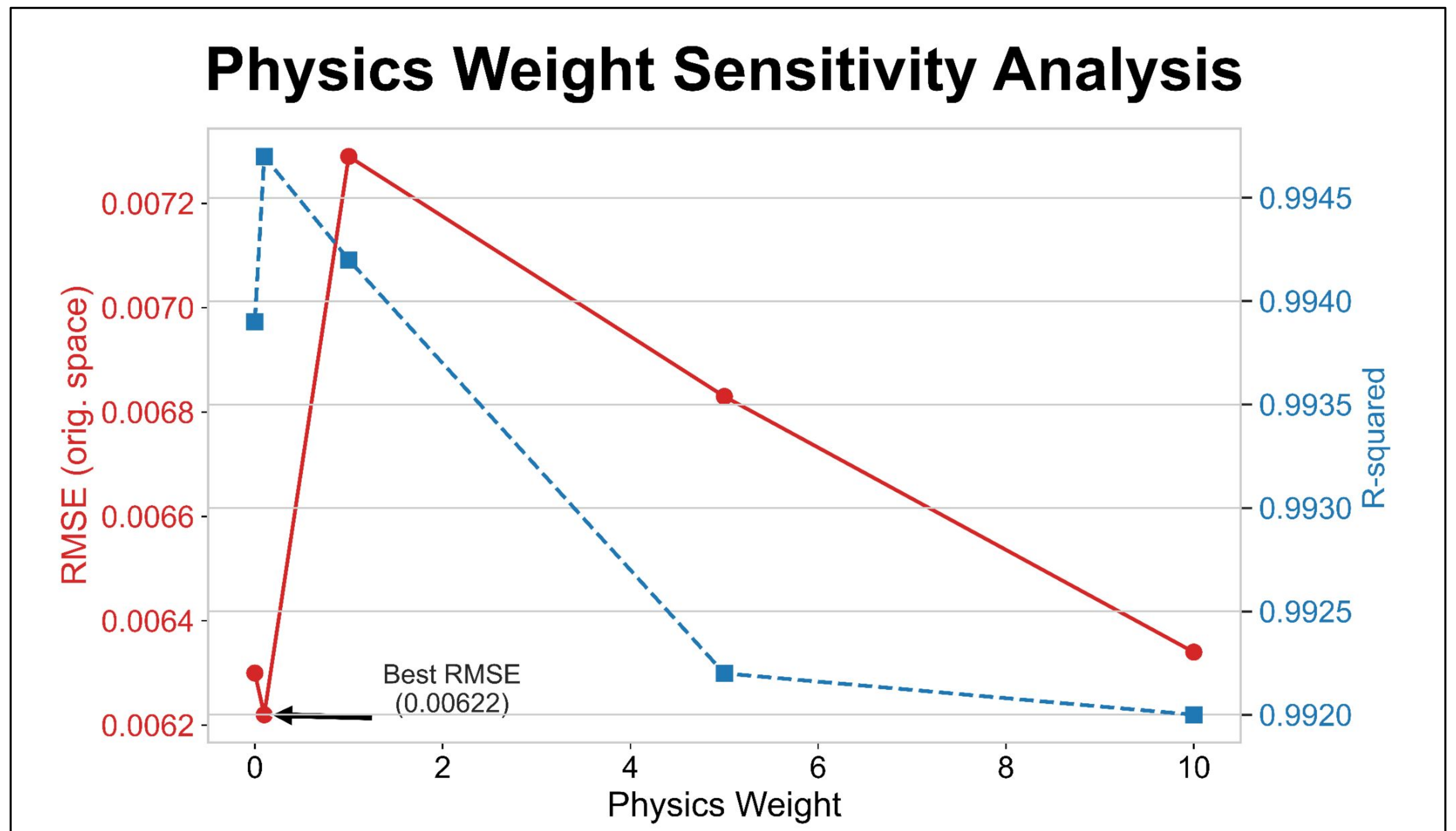
- **Economic Policy Uncertainty Index**: Tracks news articles for uncertainty in geopolitical events and policies.
- **Tech Sentiment: Tweets** and commentaries based on S&P500, scored via market sentiment model **FINBERT**

Experiments

- **Time-Price Module**: PINN Model
- **Baseline Feature Module:** Pure data-driven (MLP, Gated LSTM) approach with traditional data
- **Enhanced Feature Module:** Data-driven model with alternative data (MLP or LSTM variants)
- **Hybrid Model:** Combine PINN with feature modules

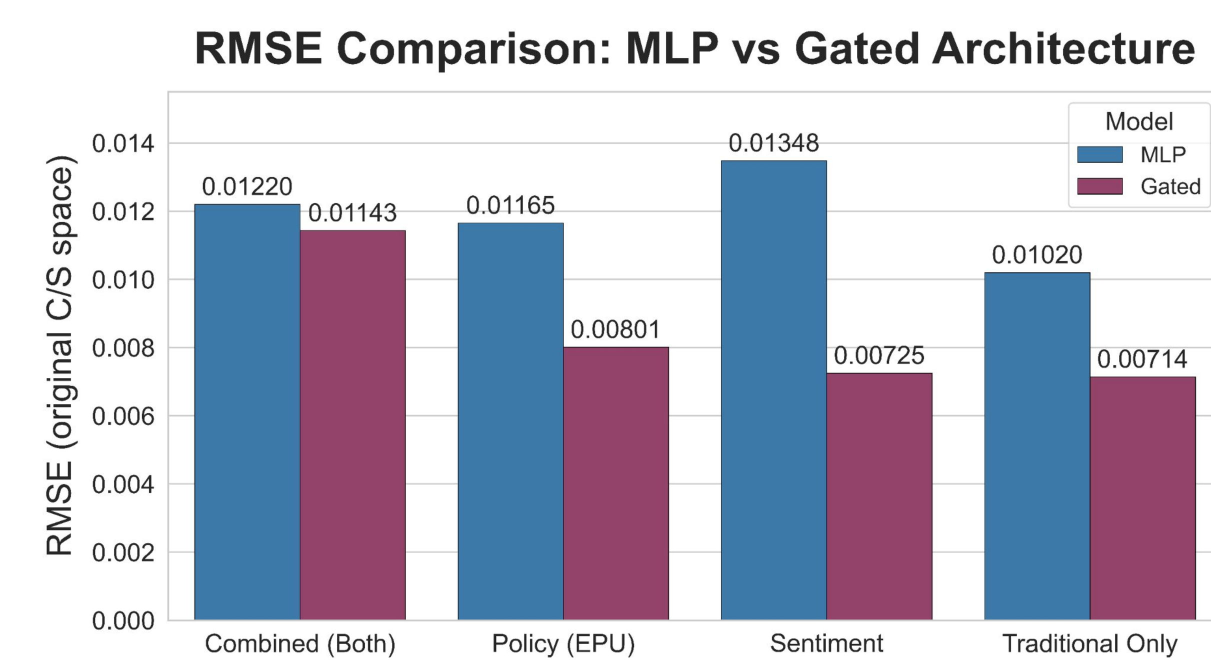
Evaluation Metrics: RMSE, MAE

Hypotheses: a) The hybrid models will perform better than the respective baseline models and b) the models with alternative data will perform better than the models without

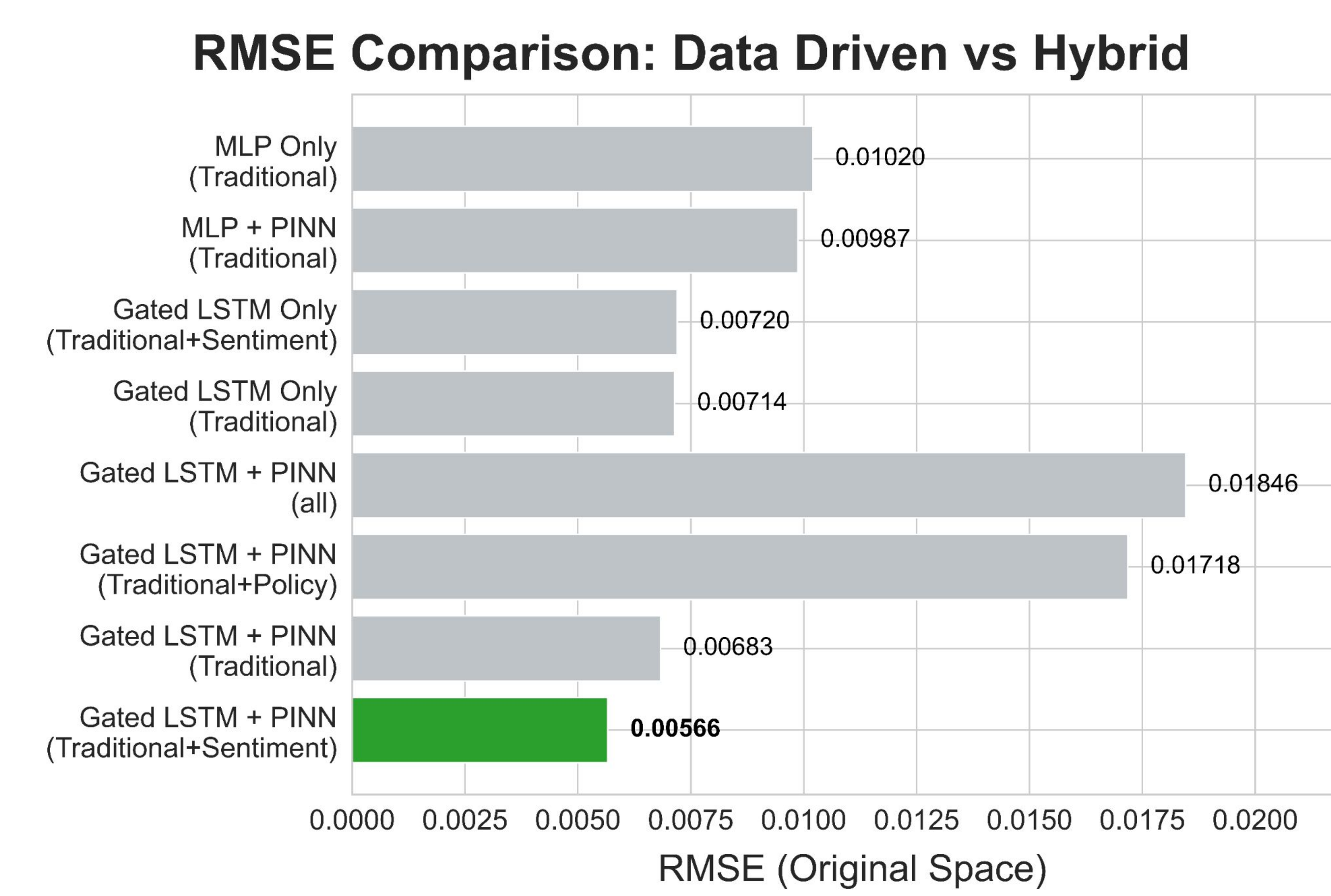


Sensitivity analysis of the physics weight λ reveals an optimal balance at λ=0.1, minimizing prediction error before performance degrades at higher weights

Results



Performance comparison showing the **Gated LSTM architecture (red)** consistently outperforming the **standard MLP (blue)** across all data configurations



Alternative Data Enhances Hybrid Performance: With a single alternative data source, the hybrid architecture achieves superior accuracy compared to traditional financial features alone.

Conclusion

- Gated residual architecture lowers RMSE and MAE, particularly with alternative data sources
- Feature modules drive significant performance gains, surpassing the marginal benefit of physics constraints alone
- Hybrid models statistically outperform purely data-driven approaches
- Market sentiment complements both theoretical and historical data

Future Work: Attention-based networks to reduce conflicting signals, and applying PINN framework for assets with limited data