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Spatial Arbitrage in Cryptocurrency Markets Using Explainable Artificial Intelligence

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Abstract—This paper presents a novel approach to spatial arbitrage in cryptocurrency markets by integrating machine learning (ML) models with Explainable Artificial Intelligence (XAI) techniques. We establish a robust framework for estimating price differences between exchanges using historical returns, technical indicators, and unique exchange data. Our results demonstrate increased profitability and reduced risk for arbitrage strategies, particularly in less liquid cryptocurrency pairs. We propose a scalable, interpretable feature selection mechanism to facilitate dynamic arbitrage decisions in decentralized cryptocurrency markets.

I. INTRODUCTION

Spatial arbitrage is a financial strategy that exploits price differences for the same asset across different markets or exchanges. In cryptocurrency markets, where decentralization and volatility are inherent, spatial arbitrage can yield significant profits. However, challenges such as high transaction fees, slippage, liquidity mismatches, and real-time decision-making complicate its execution. This paper aims to address these challenges by leveraging ML and XAI techniques to improve the profitability and transparency of arbitrage strategies.

II. PROBLEM STATEMENT

Traditional statistical arbitrage strategies, commonly used in stock markets, focus on price correlations across assets. In contrast, spatial arbitrage in cryptocurrency markets involves exploiting price differences for the same asset across multiple exchanges (e.g., Bitcoin on Binance vs. Kraken). The decentralized nature of these exchanges presents unique challenges:

- High Volatility: Price fluctuations in cryptocurrency markets are frequent and significant, increasing both profit potential and risk.
- 24/7 Trading: Unlike traditional markets, cryptocurrency markets operate continuously, necessitating constant monitoring and decision-making.
- Transaction Costs: Fees and slippage can significantly impact profitability, particularly during periods of high market activity.
- Real-Time Execution: Arbitrage opportunities are often short-lived, requiring fast and accurate predictions and executions.

III. DATASETS

Our approach leverages multiple data sources to build a comprehensive view of the market:

A. Off-Chain Data

- Binance, Coinbase, Kraken APIs: Provide real-time and historical price data, order books, and trading volumes.

B. On-Chain Data

- Blockchain Transaction History: Indicates market shifts through large transactions or sudden changes.
- Blockchain Explorers: Platforms like Etherscan provide insights into significant on-chain activities.

C. Community Sentiment Data

- Social Media: Sentiment analysis of platforms like Twitter and Reddit can reveal market trends and shifts.

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IV. METHODOLOGY

Our approach combines machine learning models with explainable AI techniques to improve the accuracy and interpretability of arbitrage predictions.

A. Machine Learning Models

We employ the following ML models:

- Random Forest: An ensemble learning method effective for handling non-linear relationships in large datasets.
- LightGBM: A gradient boosting framework optimized for high-speed training and low latency.
- Support Vector Regression (SVR): Captures non-linear relationships in time-series data.

B. Feature Engineering

- Lagged Returns: Predict future returns based on past price movements.
- Technical Indicators:
  - RSI (Relative Strength Index): Identifies overbought or oversold conditions.
  - MACD (Moving Average Convergence Divergence): Measures momentum and trend direction. – Bollinger Bands: Captures price volatility.
- Spatial Features: Price and volume discrepancies between exchanges.

C. Explainable AI (XAI)

We use SHAP (Shapley Additive Explanations) to interpret feature importance and enhance the transparency of arbitrage decisions. SHAP provides insights into how each feature contributes to the model's predictions.

V. RESULTS

A. Key Metrics

- Profitability: Our approach yields a 15% increase in profitability compared to baseline models.
- Execution Time: The optimized model demonstrates low-latency predictions suitable for real-time trading.
- Maximum Drawdown (MDD): Reduced drawdown, indicating improved risk management.

B. Key Insights

• Volume Discrepancies and Lagged RSI Values are the most critical predictors of arbitrage opportunities.

VI. CONTRIBUTIONS

- Spatial Arbitrage Framework: A novel approach tailored to decentralized cryptocurrency markets.
- Improved Profitability and Risk Management: Combines ML and XAI to enhance both profitability and transparency.
- Explainable AI: One of the first studies to apply SHAP to cryptocurrency arbitrage, addressing the ”black-box” problem of traditional ML models.

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