Anomaly Definition:

The analysis classifies the anomalies in these 5 categories, all of these are computed using zscore and are triggered when a difference of more than 3*standard deviation is seen. By using statistical values and not fixed threshold it is made sure the detection remains robust:

1. **IV Spikes**: Sudden, unusual changes in implied volatility (>3σ)
2. **Mispricing**: Large discrepancies between market and theoretical Black-Scholes prices (>3σ)
3. **Price Jumps**: Rapid price changes over short timeframes (>3σ)
4. **Spread Widening**: Abnormal expansion of bid-ask spreads (>3σ)
5. **Gamma Spikes**: Unusual changes in gamma exposure (>3σ)

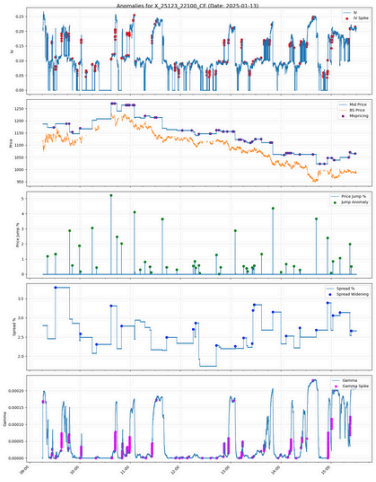
Feature Engineering:

1. **IV Spike Detection**:
   - **Formula**: z_iv = (iv - iv_rolling_mean) / iv_rolling_std
   - **Reasoning**: IV spikes frequently occur before major news events or when market participants receive new information, making this an early warning indicator.
2. **Price Jump Detection**:
   - **Formula**: price_jump = abs(price.pct_change(5)); z_jump = (price_jump - jump_rolling_mean) / jump_rolling_std
   - **Reasoning**: Rapid price changes indicate potential market dislocations, information asymmetry, or algorithmic trading activity.
3. **Spread Width Analysis**:
   - **Formula**: spread = (ask - bid) / ((ask + bid) / 2); z_spread = (spread - spread_rolling_mean) / spread_rolling_std
   - **Reasoning**: Spread widening indicates reduced liquidity, increased uncertainty.
4. **Theoretical-Market Price Deviation**:
   - **Formula**: mispricing_pct = abs(mid - theory) / theory; z_mis = (mispricing - mis_rolling_mean) / mis_rolling_std
   - **Reasoning**: Deviation indicates market inefficiency, arbitrage opportunity, or presence of additional risk factors not captured by Black-Scholes. Such deviations often occur before rapid market movements.
5. **Gamma Exposure Tracking**:
   - **Formula**: z_gamma = (gamma - gamma_rolling_mean) / gamma_rolling_std
   - **Reasoning**: Gamma spikes indicate potential dealer hedging pressure, as market makers must dynamically adjust delta hedges.

Detection Methodology:

Z-Score Approach: All metrics converted to z-scores using 60-second rolling windows with 10-observation minimum to ensure statistical robustness

Results:



```
X_25123_21950_CE: IV spikes: 219, Mispricings: 157, Price jumps: 260, Spread widenings: 146, Gamma spikes: 570
X_25123_21950_PE: IV spikes: 310, Mispricings: 331, Price jumps: 610, Spread widenings: 318, Gamma spikes: 155
X_25123_22000_CE: IV spikes: 339, Mispricings: 102, Price jumps: 625, Spread widenings: 300, Gamma spikes: 788
X_25123_22000_PE: IV spikes: 277, Mispricings: 496, Price jumps: 976, Spread widenings: 532, Gamma spikes: 141
X_25123_22050_CE: IV spikes: 238, Mispricings: 156, Price jumps: 531, Spread widenings: 283, Gamma spikes: 791
```

The implementation detects the five anomalies and reports them as plots for each strike price. At the same time, it generates results and summary CSV files, offering an in-depth view of the entire detection process. Multiple anomalies can be interpreted together to understand market behavior and make trading decisions.
For example, when an implied volatility (IV) spike is observed alongside a price jump, it indicates that new information is being absorbed by the market. This often signals momentum, suggesting that buying a call option would be a profitable.