HG Futures Curve Analysis

Analysis Results Report

futures_curve Pipeline

January 19, 2026

Run provenance

- data_dir: `/home/austinli/Dropbox/Future_project_1/data_parquet`
- research_dir: `/home/austinli/Dropbox/Future_project_1/research_outputs`
- generated (UTC): 2026-01-19 11:22:37 UTC
- trades summary mtime (UTC): 2026-01-19 10:15:28 UTC

Contents

1 Executive Summary

This report documents a reproducible analysis of the **HG** front calendar spread ($S1 = F2 - F1$) and evaluates two simple systematic rules (EOM and DTE) under an explicit execution and transaction-cost model.

1.1 Key Findings

- **Data coverage:** 202 contracts; 8,318,956 1-minute bars; 2008-01-02 to 2024-12-27 (4,385 trade dates).
- **Market structure:** HG is often in contango, with measurable variation across the contract lifecycle (DTE) and around month-end (EOM).
- **Profitability (net of costs):** EOM is profitable in this sample (net P&L +$18,720.31, Sharpe 1.06); DTE is not (net P&L -$29,890.00, Sharpe -1.42).
- **Interpretation:** Results are conditional on the execution proxy (bucket/daily closes) and the transaction cost model; sensitivity analyses are provided in Sections 9–10.

1.2 How to read this report

Sections 2–6 define the data transformations, bucketing, and feature construction. Sections 7–8 define the strategies and show baseline backtest results. Sections 9–10 provide robustness checks (transaction costs, stop-loss sensitivity) and risk diagnostics.

2 Data and Preprocessing

2.1 Raw data format

Input files are headerless 1-minute OHLCV TXT/CSV in the form:

```
(timestamp, open, high, low, close, volume)
```

Timestamps are typically *naive* (no timezone). The pipeline infers the raw timezone by choosing the conversion to exchange time that minimizes activity during the CME maintenance hour (16:00–16:59 CT).

2.2 Exchange time and trade date

All timestamps are converted to **US/Central** (CME exchange time). A **trade date** is assigned using the CME Globex boundary:

- If timestamp $\geq$ 17:00 CT, trade date = next calendar date.
- Otherwise, trade date = same calendar date.

2.3 Bucketing (hourly session schema)

Minute bars are aggregated into a 10-bucket schema per trade date. Buckets are defined so that the trade-date boundary (17:00 CT) is also the start of bucket 8. Bucket 0 (16:00–16:59 CT) is treated as QC-only.

Bucket	Start (CT)	End (CT)	Description
0	16:00	16:59	Maintenance hour (16:00-16:59 CT) - should be empty; QC only
1	09:00	09:59	US session hour 1
2	10:00	10:59	US session hour 2
3	11:00	11:59	US session hour 3
4	12:00	12:59	US session hour 4
5	13:00	13:59	US session hour 5
6	14:00	14:59	US session hour 6
7	15:00	15:59	US session hour 7
8	17:00	20:59	Asia/Europe overlap (post reopen)
9	21:00	02:59	Overnight (cross-midnight)
10	03:00	08:59	Pre-US session

Table 1: Bucket schema in exchange time (US/Central). Note: buckets 8 and 9 occur on the *prior* calendar day but belong to the next trade date.

2.4 Aggregation outputs

The pipeline produces:

- Contract-level bucket OHLCV (Stage 1)
- Deterministic curve panel (F1..F12) and spreads (Stage 2)
- Daily US-session $S1$ proxy with EOM labels (Stage 3)
- Backtests with trade logs and equity curves (Stage 4)

3 Data Cleaning and Quality

3.1 Validation Checks Performed

- **OHLC Consistency:** Verified High $\geq$ max(Open, Close) and Low $\leq$ min(Open, Close) for all bars
- **Outliers:** Large spread moves are flagged for review (retained unless explicitly excluded for a specific statistic)
- **Expiry constraint:** Verified DTE > 0 for all eligible F1 labels (no expired-contract trading)
- **Missing data:** Spread observations require both legs to have a print in the bucket; missing prints propagate to NA spreads (no forward-fill)

3.2 Diagnostics Summary

symbol	ohlc_issues	zscore_events	expiry_violations	spread_discrepancies	data_gaps
HG	0	1	0	0	0

Table 2: Data quality diagnostics from pipeline validation checks.

3.3 Outlier Handling

Outliers (Z-score > 3) were handled as follows:

- Retained in the dataset for transparency
- Flagged in diagnostics for researcher review
- Where a statistic is sensitive to extremes, robustness checks are reported explicitly

4 Feature Engineering

4.1 Calendar Spread Calculation

The front calendar spread (S1) is calculated as:

$$S1_{raw}(t) = F2(t) - F1(t)$$

where F1 and F2 are the front and second-month contracts respectively.

4.2 Spread Normalization

For cross-commodity and cross-time comparisons, we normalize:

$$S1_{pct}(t) = \frac{F2(t) - F1(t)}{F1(t)}$$

This expresses the spread as a fraction of the front-month price (multiply by 100 for percentage points when desired).

4.3 Days-to-Expiry (DTE)

DTE is calculated as business days remaining until F1 contract expiration:

- Computed using the CME trading calendar (weekends and exchange holidays excluded)
- Business-day DTE (`F1_dte_bdays`) is computed on the trade-date axis
- Hour-based DTE (`F1_dte_hours`) is computed from bucket-end timestamps (for diagnostics)

4.4 Roll Detection

Roll timing is detected via F2 volume share:

$$s(t) = \frac{V_{F2}(t)}{V_{F1}(t) + V_{F2}(t)}$$

Roll phases: Start ($s \geq 25\%$), Peak ($s \geq 50\%$), End ($s \geq 75\%$).

4.5 End-of-Month (EOM) labeling and daily proxy

EOM offsets are defined on the business-day calendar:

- `EOM-0`: last business day of the month
- `EOM-1`: second-to-last business day
- `EOM-k`: k business days before month-end

For EOM analysis and the EOM backtest, we use a daily US-session proxy for $S1$ (09:00–15:59 CT):

- Compute a volume-weighted average of bucket $S1$ within the US session.
- If the $(S1\_near, S1\_far)$ pair changes intraday (e.g., around expiry), the day is filtered to a single representative pair to avoid mixing different spreads.

5 Spread Characteristics

5.1 Term Structure Analysis

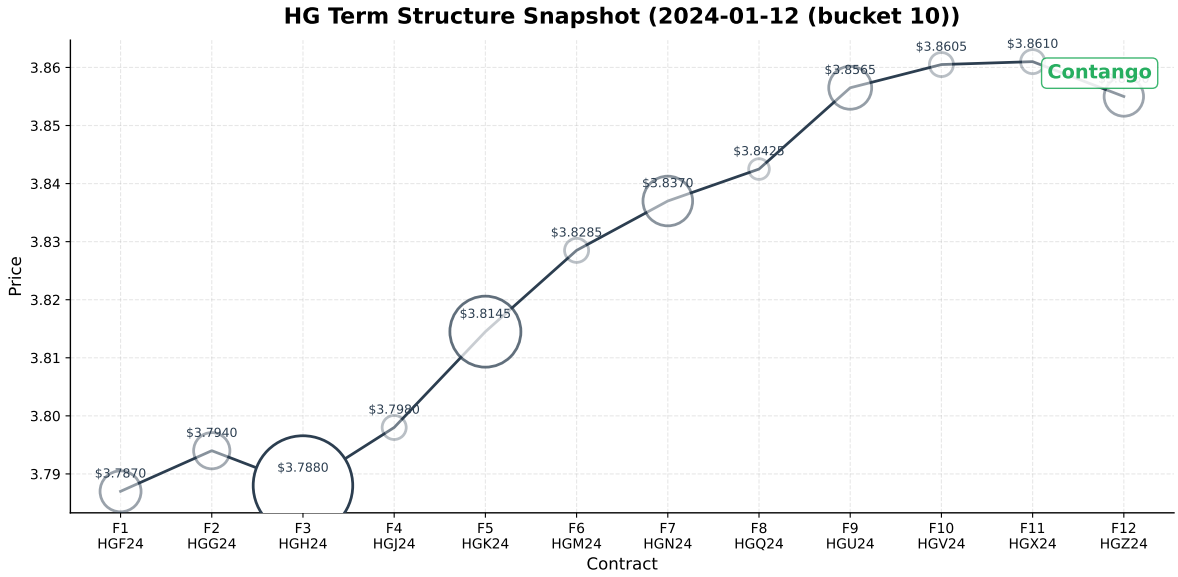

Figure 1: HG term structure snapshot showing price curve across contracts F1-F12. Upward-sloping curve indicates contango; downward-sloping indicates backwardation.

Interpretation: The term structure snapshot captures the price relationship across contract months at a single point in time. For HG, the curve typically exhibits contango, reflecting storage costs and convenience yield dynamics.

5.2 DTE Profile

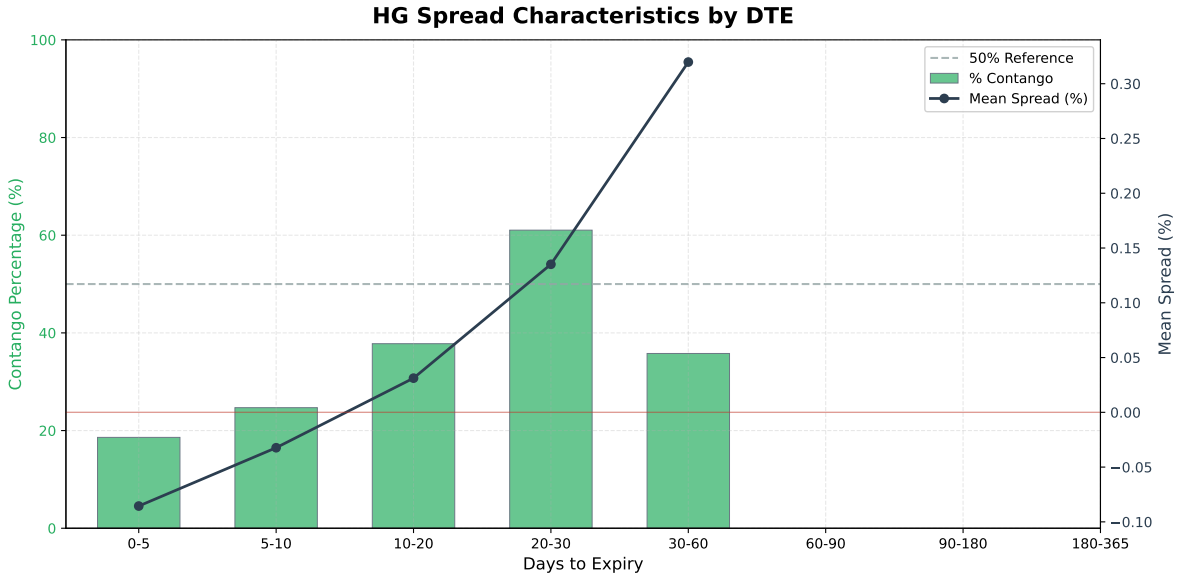

Figure 2: Spread characteristics by days-to-expiry showing how contango/backwardation frequency and mean spread evolve across the contract lifecycle.

dte_bin	count	mean	std	min	max	median	pct_contango	mean_pct	median_pct
0-5	4187	-0.001	0.004	-0.030	0.037	-0.000	18.604	-0.086	-0.022
5-10	4918	-0.000	0.004	-0.060	0.027	0.000	24.688	-0.032	0.012
10-20	12520	0.000	0.004	-0.024	0.053	0.001	37.788	0.031	0.073
20-30	1208	0.001	0.003	-0.014	0.012	0.002	61.036	0.135	0.153
30-60	135	0.003	0.004	-0.008	0.020	0.003	35.786	0.320	0.313
60-90	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
90-180	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
180-365	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Table 3: Spread statistics by DTE bin. Values in percentage terms where noted.

Interpretation: The DTE profile reveals systematic patterns in spread behavior as contracts approach expiry. Near-expiry periods (DTE < 10) often show increased volatility due to roll activity.

5.3 Contango/Backwardation Analysis

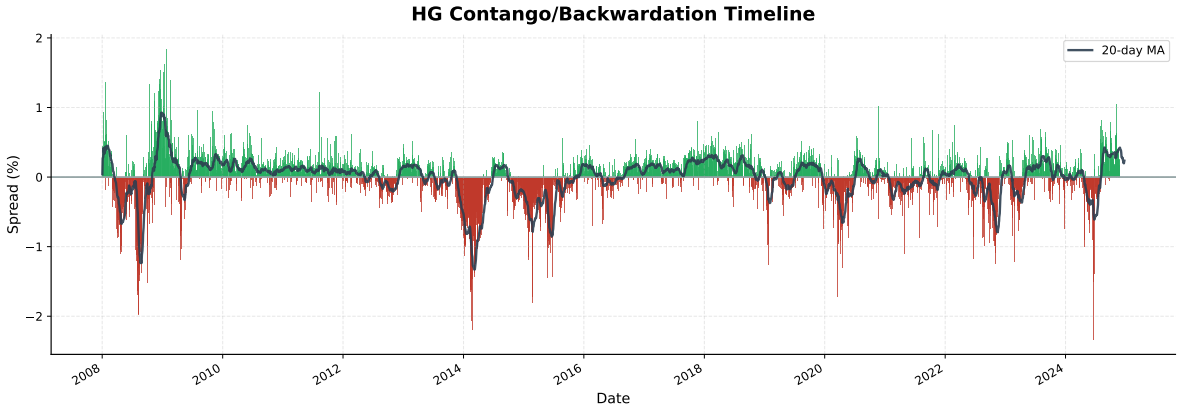

Figure 3: Timeline of contango (green) and backwardation (red) states across the sample period. Contango predominates but backwardation episodes occur.

6 Seasonality Analysis

6.1 Monthly Patterns

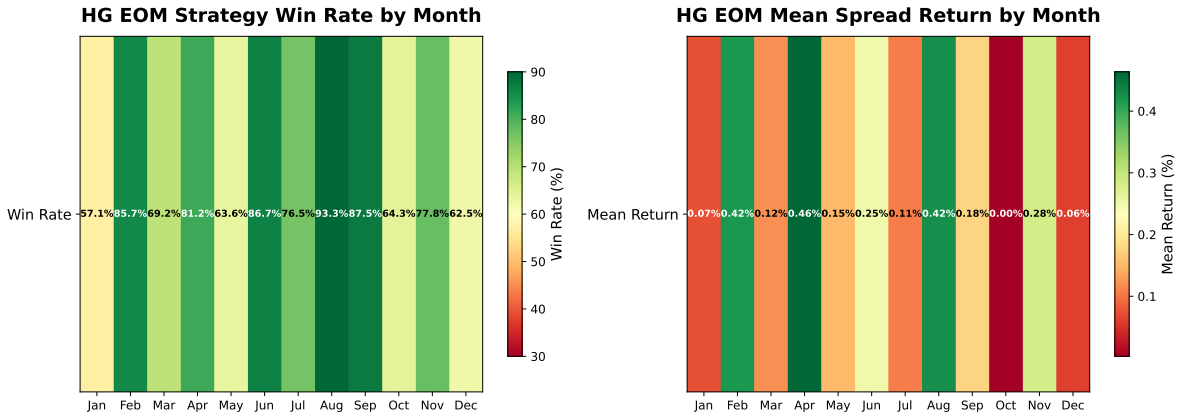

Figure 4: EOM strategy win rate and mean return by calendar month. Darker colors indicate stronger performance.

month	count	std_return	total_return	win_rate	month_name	mean_return_pct
1	14	0.00	0.01	57.14	Jan	0.07
2	14	0.00	0.06	85.71	Feb	0.42
3	13	0.00	0.02	69.23	Mar	0.12
4	16	0.00	0.07	81.25	Apr	0.46
5	11	0.00	0.02	63.64	May	0.15
6	15	0.00	0.04	86.67	Jun	0.25
7	17	0.00	0.02	76.47	Jul	0.11
8	15	0.00	0.06	93.33	Aug	0.42
9	16	0.00	0.03	87.50	Sep	0.18
10	14	0.00	0.00	64.29	Oct	0.00
11	9	0.00	0.03	77.78	Nov	0.28
12	16	0.00	0.01	62.50	Dec	0.06

Table 4: Monthly seasonality statistics for EOM spread returns.

Statistical Interpretation: Monthly patterns should be interpreted with caution given the limited number of observations per month-year combination. The table shows mean returns, but confidence intervals may be wide for months with fewer observations.

6.2 Bucket-Level Analysis

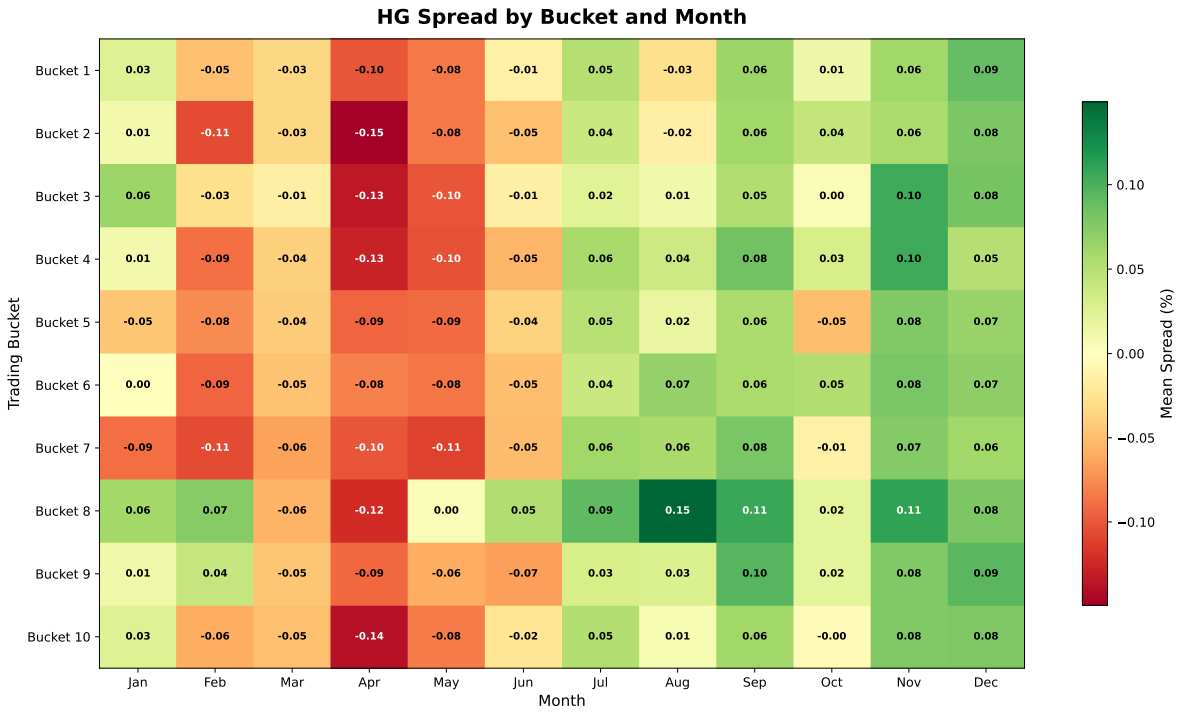

Figure 5: Mean spread by trading bucket and calendar month, showing intraday and seasonal interaction effects.

6.3 End-of-Month Effect

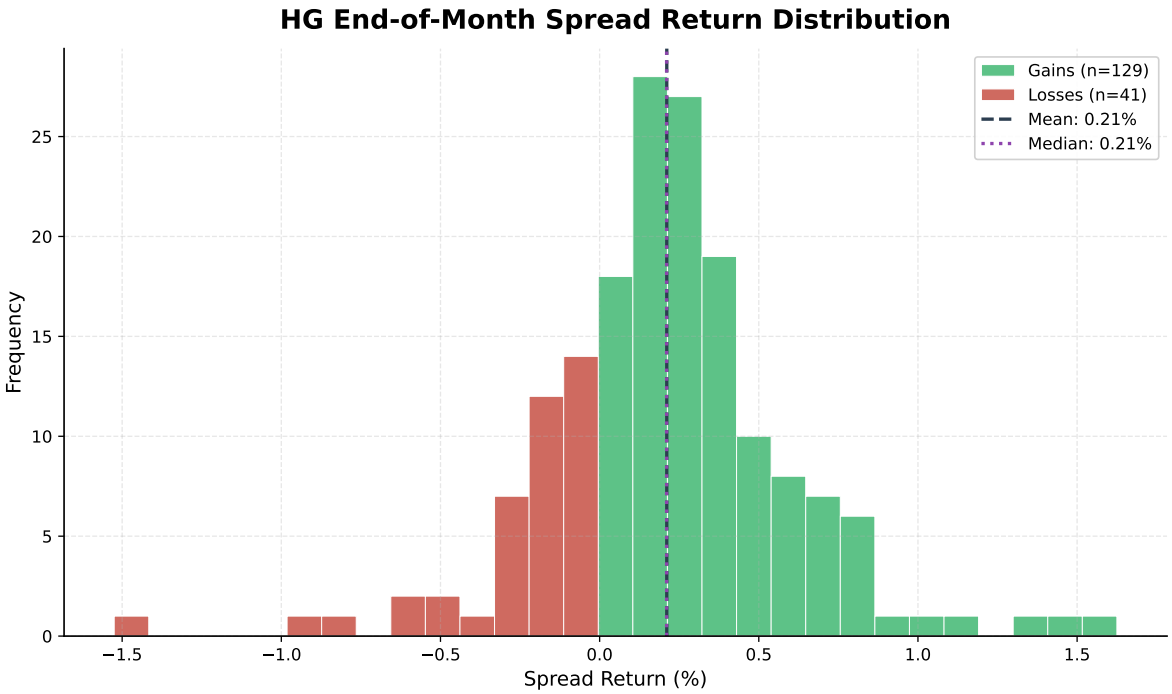

Figure 6: Distribution of end-of-month spread returns showing positive skew and the empirical shape of the EOM window returns (descriptive; no costs).

Economic hypothesis (informal): End-of-month effects in commodity spreads may reflect:

- Index rebalancing by commodity funds
- Month-end position squaring by dealers
- Futures roll timing for commodity indices (e.g., GSCI, BCOM)

7 Roll Dynamics

7.1 Roll Event Study

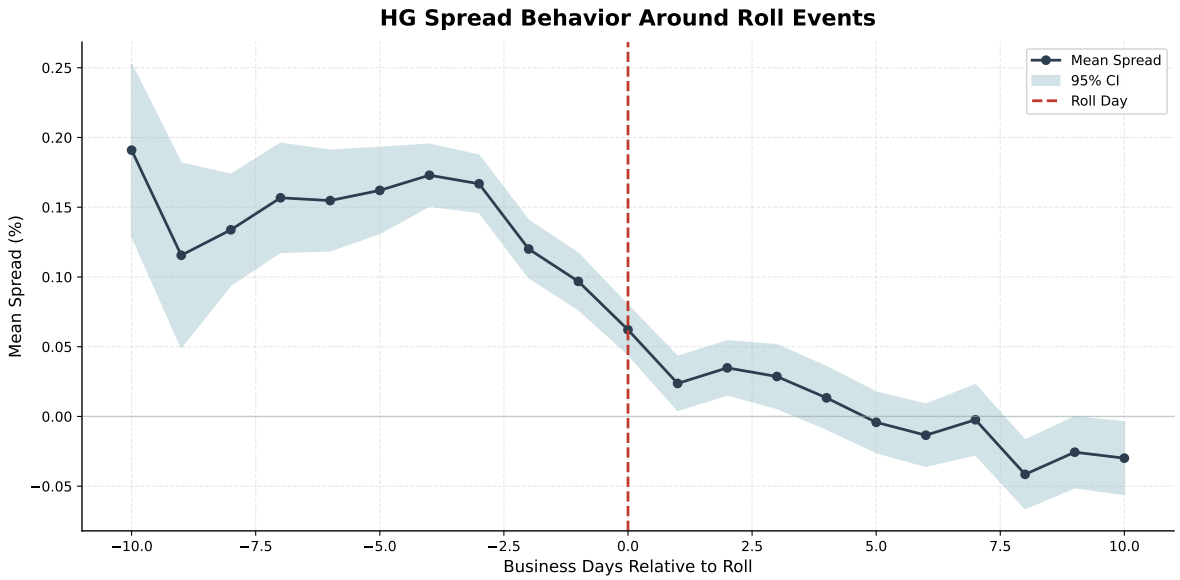

Figure 7: Mean spread behavior around roll events with 95% confidence bands. Day 0 = roll peak (F2 volume share > 50%).

Interpretation: The event study aligns all roll events at day 0 (roll peak) and computes the average spread path. Confidence bands indicate the variability across roll events.

7.2 Volume Share Evolution

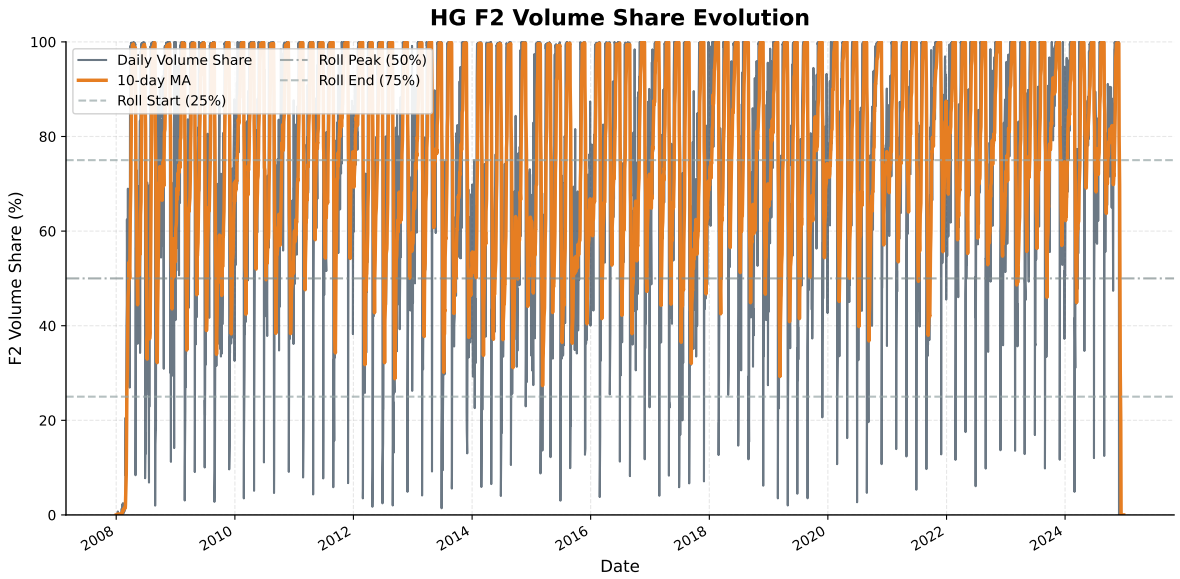

Figure 8: F2 volume share evolution showing the characteristic S-curve transition pattern during contract rolls.

8 Strategy Backtesting

8.1 Strategy Definitions

Strategy	Entry Rule	Exit Rule	Direction
DTE	First signal when $5 <$ `F1_dte_bdays` ≤ 15 (executed next observation)	First signal when `F1_dte_bdays` ≤ 5 (executed next observation)	Long $S1$
EOM	Executed entry on `EOM-3` (signal generated on `EOM-4`)	Executed exit on `EOM-1` (signal generated on `EOM-2`)	Long $S1$

8.2 Configuration Parameters

Parameter	Value	Description
Slippage	1 tick	\$12.50 per fill (HG)
Commission	\$2.50	Per contract per side
Position size	1 spread	1 F1 vs. 1 F2 contract
Round-trip cost	\$60.00	4 fills $\times$ (\$12.50 + \$2.50)

8.3 Performance Summary

strategy	total_trades	win_rate	gross_pnl	total_costs	total_pnl	sharpe_ratio	max_drawdown_pct	profit_factor
DTE	154	29.22	-20650.00	9240.00	-29890.00	-1.42	-30.66	0.29
EOM	176	65.91	29280.31	10560.00	18720.31	1.06	-1.48	2.64

Table 5: Strategy-level performance metrics. `total_pnl` is net of transaction costs; `gross_pnl` and `total_costs` are derived from the trade logs.

8.4 Equity Curves

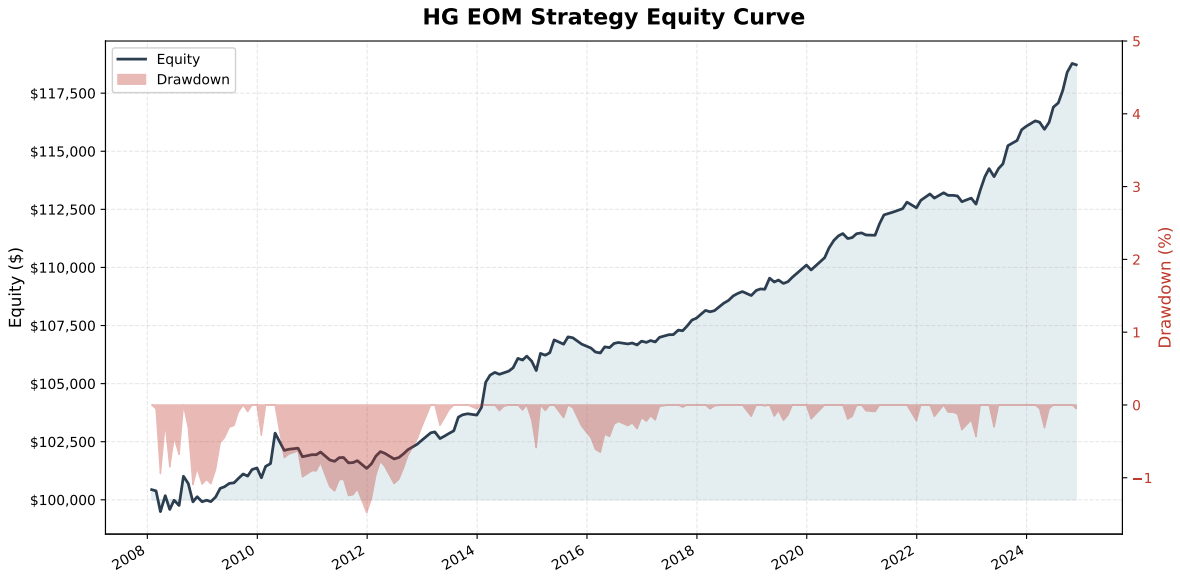

Figure 9: EOM strategy equity curve with drawdown overlay showing cumulative net P&L over time.

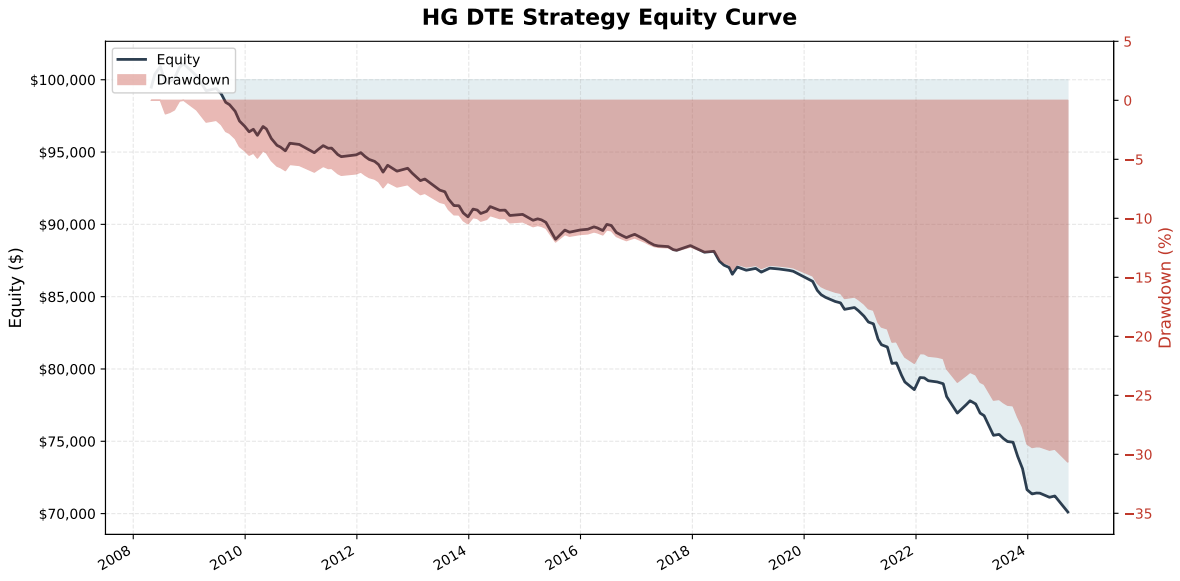

Figure 10: DTE strategy equity curve with drawdown overlay.

8.5 Strategy Comparison

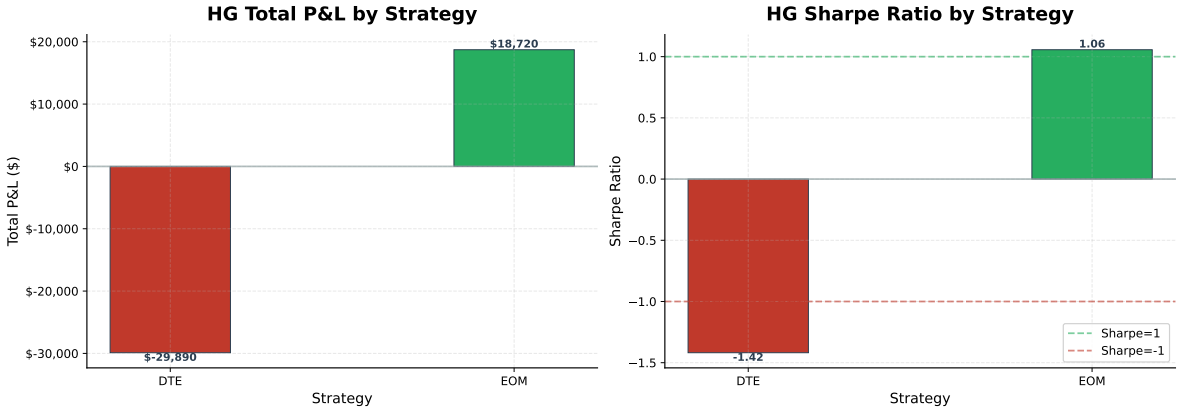

Figure 11: Comparison of total P&L and Sharpe ratio across strategies.

8.6 P&L Distribution

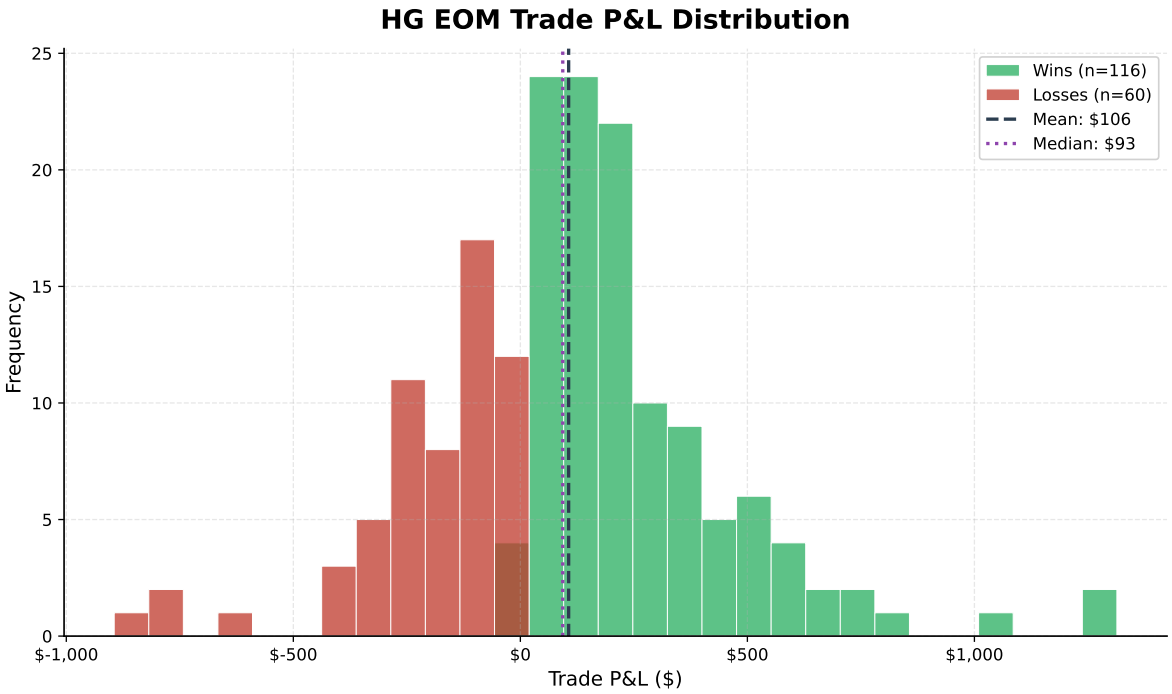

Figure 12: Distribution of trade P&L for the EOM strategy showing win/loss magnitude asymmetry.

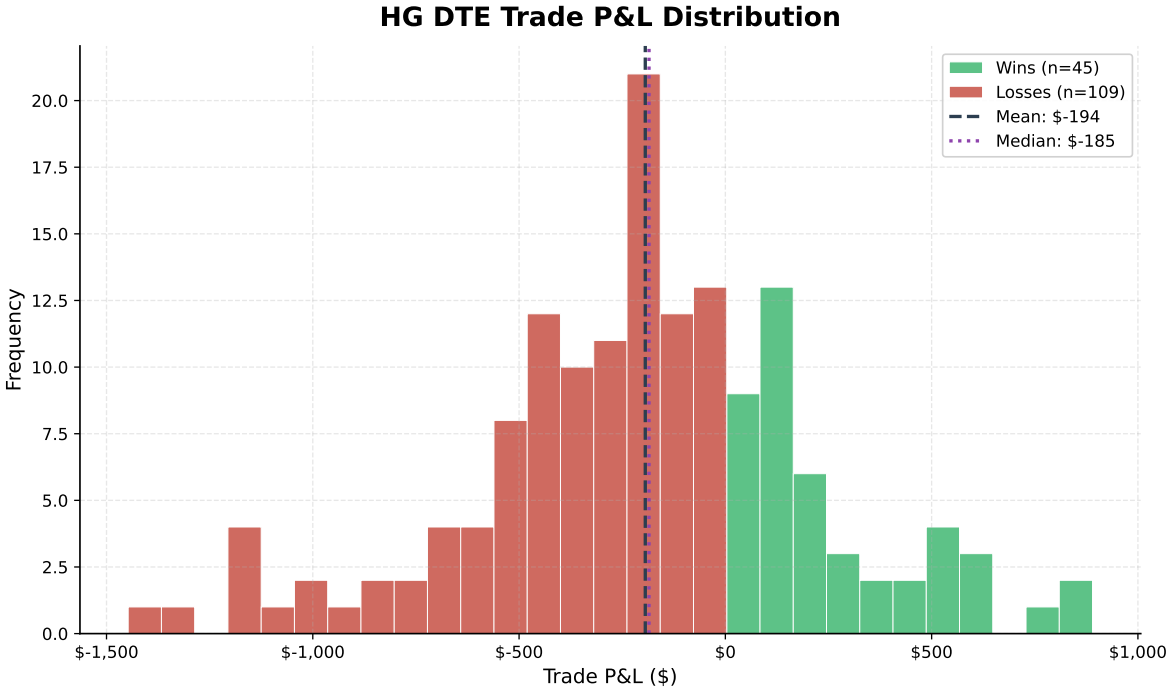

Figure 13: Distribution of trade P&L for the DTE strategy.

8.7 Monthly Returns

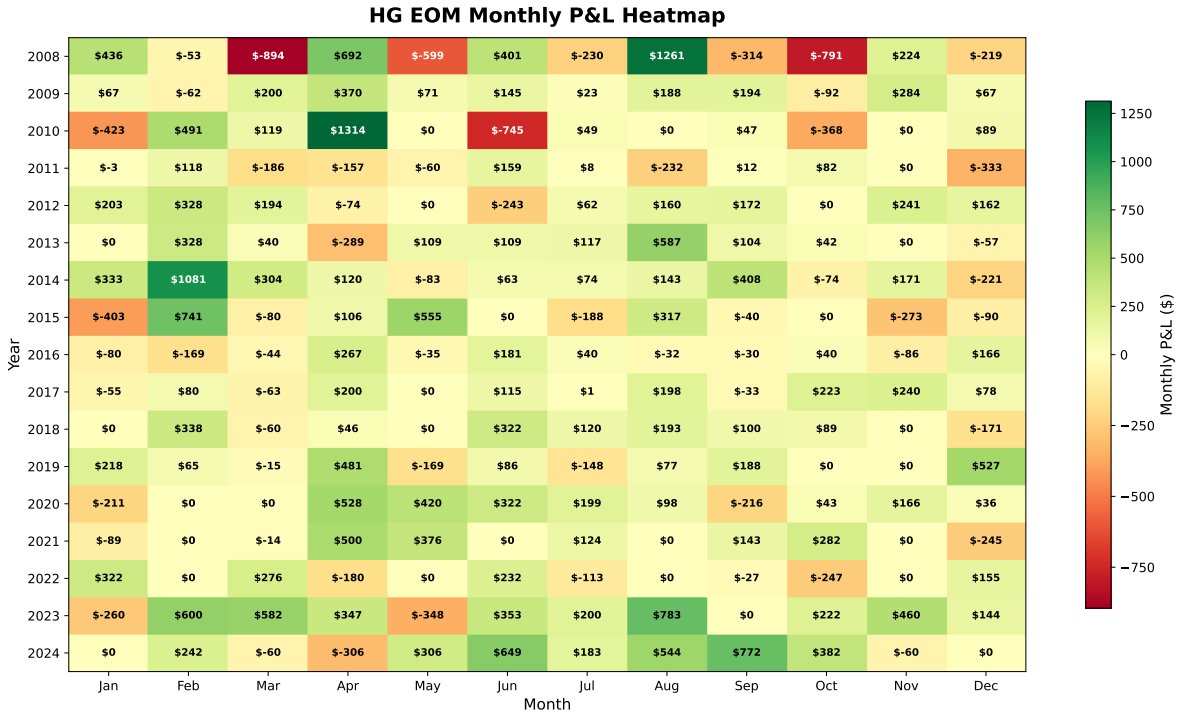

Figure 14: Year-by-month P&L heatmap for the EOM strategy showing performance consistency across time.

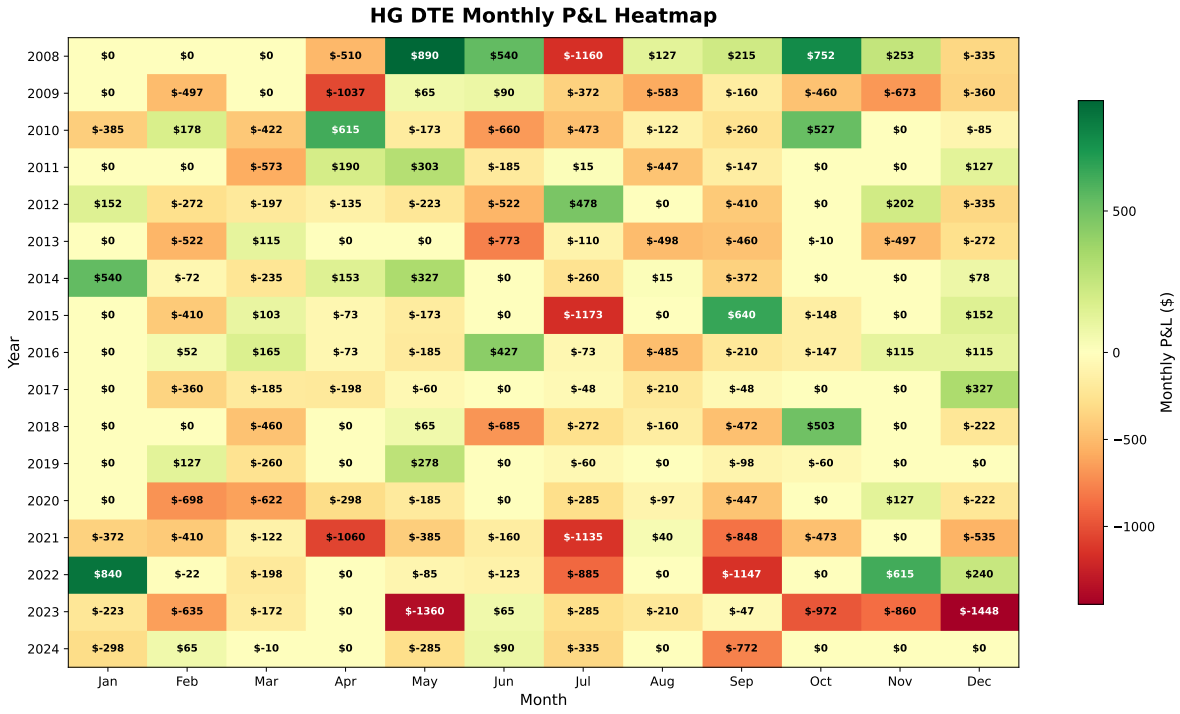

Figure 15: Year-by-month P&L heatmap for the DTE strategy.

9 Sensitivity and Robustness

9.1 Transaction Cost Sensitivity

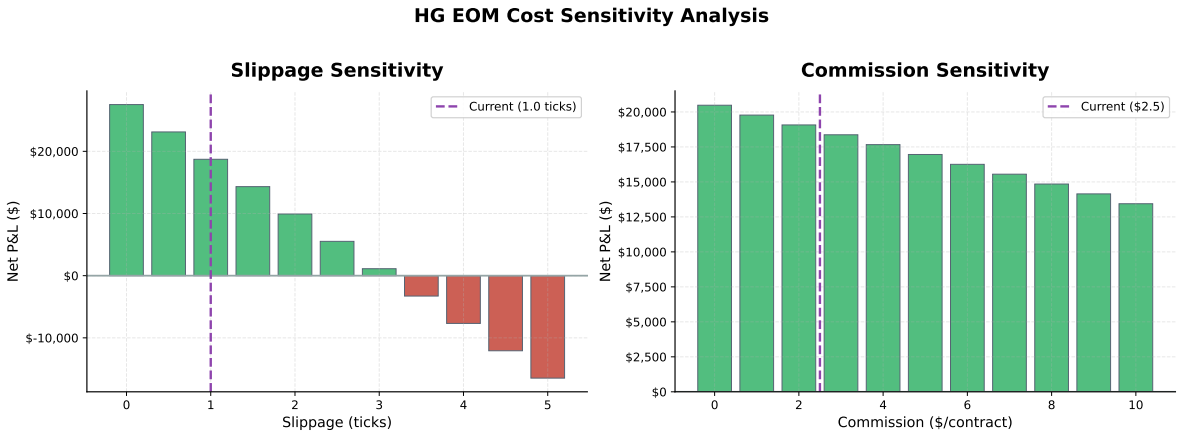

Figure 16: Strategy profitability sensitivity to slippage and commission assumptions. Vertical line indicates baseline assumption.

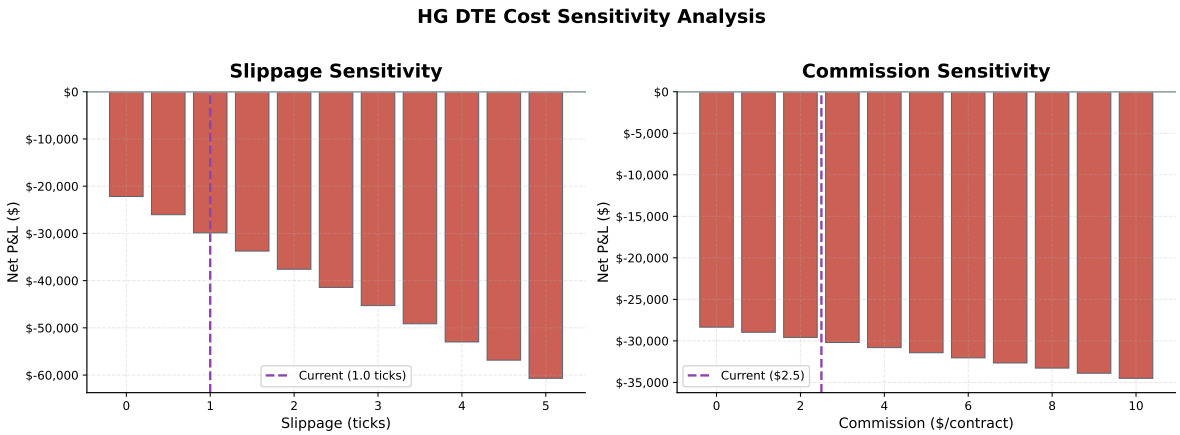

Figure 17: DTE strategy cost sensitivity to slippage and commission assumptions (same methodology as EOM).

9.2 Break-Even Analysis

Transaction costs are a critical determinant of strategy viability. The cost sensitivity figure shows:

- Net P&L across a range of cost assumptions
- Break-even point where strategy becomes unprofitable
- Margin of safety relative to realistic cost estimates

Discussion: In this run, the EOM strategy remains profitable under a wide range of costs. The DTE strategy remains unprofitable even under very low costs, indicating that (for this definition) the edge is negative before costs.

9.3 Stop-Loss Sensitivity (robustness check)

Stop losses are *not* part of the baseline definition. Here we evaluate a simple stop-loss rule as a robustness check: if the **gross** mark-to-market P&L (excluding costs) falls below `-stop_loss_usd` at an observation close, the position is closed.

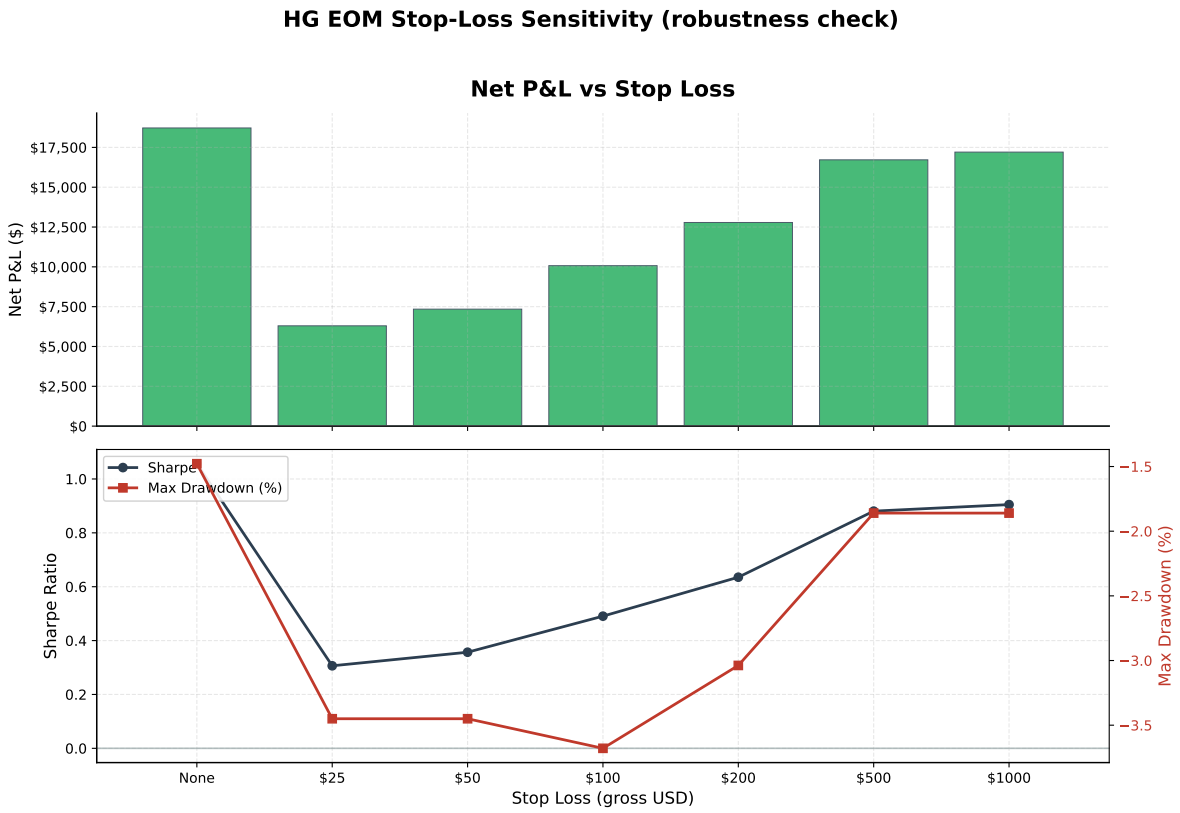

Figure 18: EOM stop-loss sensitivity.

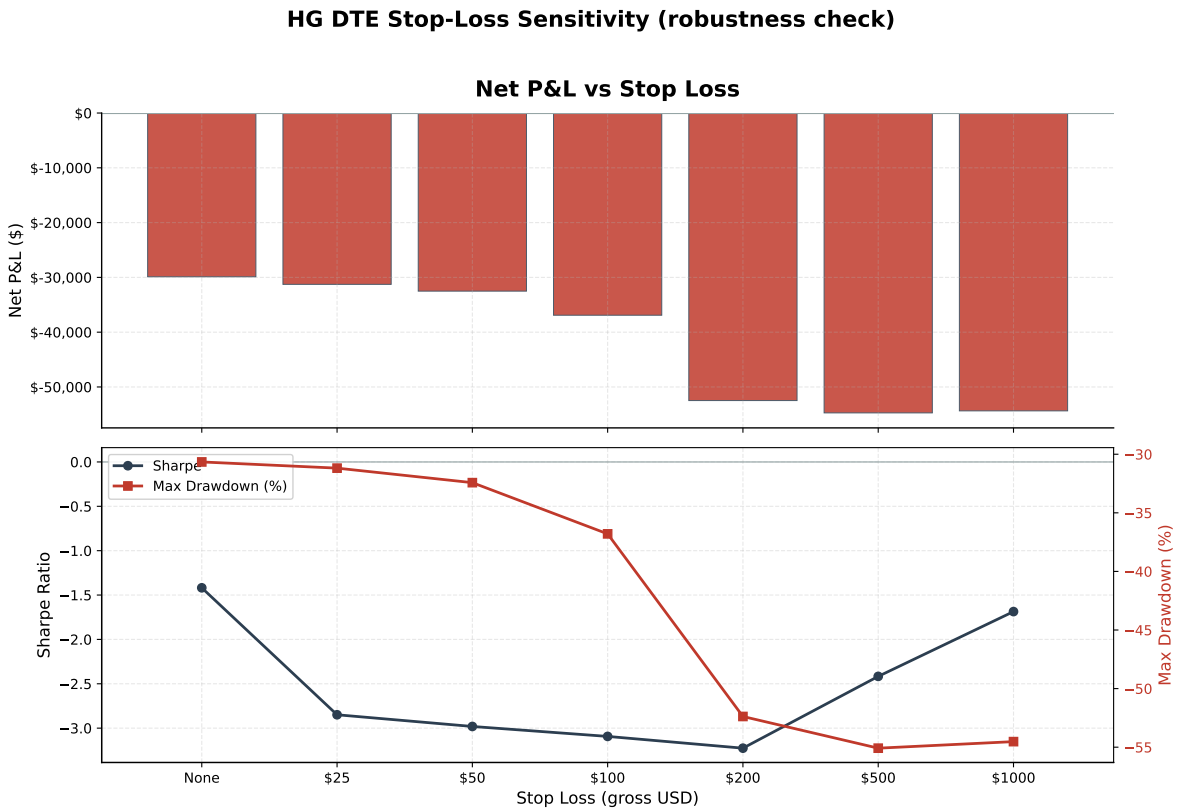

Figure 19: DTE stop-loss sensitivity.

stop_loss_usd	total_trades	win_rate	gross_pnl	total_costs	total_pnl	sharpe_ratio	max_drawdown_pct
NaN	176	65.91	29280.31	10560.00	18720.31	1.06	-1.48
25.00	178	50.00	16977.31	10680.00	6297.31	0.31	-3.45
50.00	178	52.81	18024.25	10680.00	7344.25	0.36	-3.45
100.00	177	58.19	20693.44	10620.00	10073.44	0.49	-3.68
200.00	177	62.71	23405.69	10620.00	12785.69	0.64	-3.04
500.00	176	65.34	27279.11	10560.00	16719.11	0.88	-1.86
1000.00	176	65.91	27764.56	10560.00	17204.56	0.90	-1.86

Table 6: EOM stop-loss sensitivity table (net of costs).

stop_loss_usd	total_trades	win_rate	gross_pnl	total_costs	total_pnl	sharpe_ratio	max_drawdown_pct
NaN	154	29.22	-20650.00	9240.00	-29890.00	-1.42	-30.66
25.00	127	2.36	-23650.00	7620.00	-31270.00	-2.85	-31.19
50.00	127	2.36	-24887.50	7620.00	-32507.50	-2.98	-32.42
100.00	128	4.69	-29225.00	7680.00	-36905.00	-3.09	-36.80
200.00	132	9.09	-44562.50	7920.00	-52482.50	-3.23	-52.38
500.00	137	24.09	-46512.50	8220.00	-54732.50	-2.42	-55.08
1000.00	144	28.47	-45722.50	8640.00	-54362.50	-1.69	-54.53

Table 7: DTE stop-loss sensitivity table (net of costs).

10 Risk Analysis

10.1 Rolling Performance

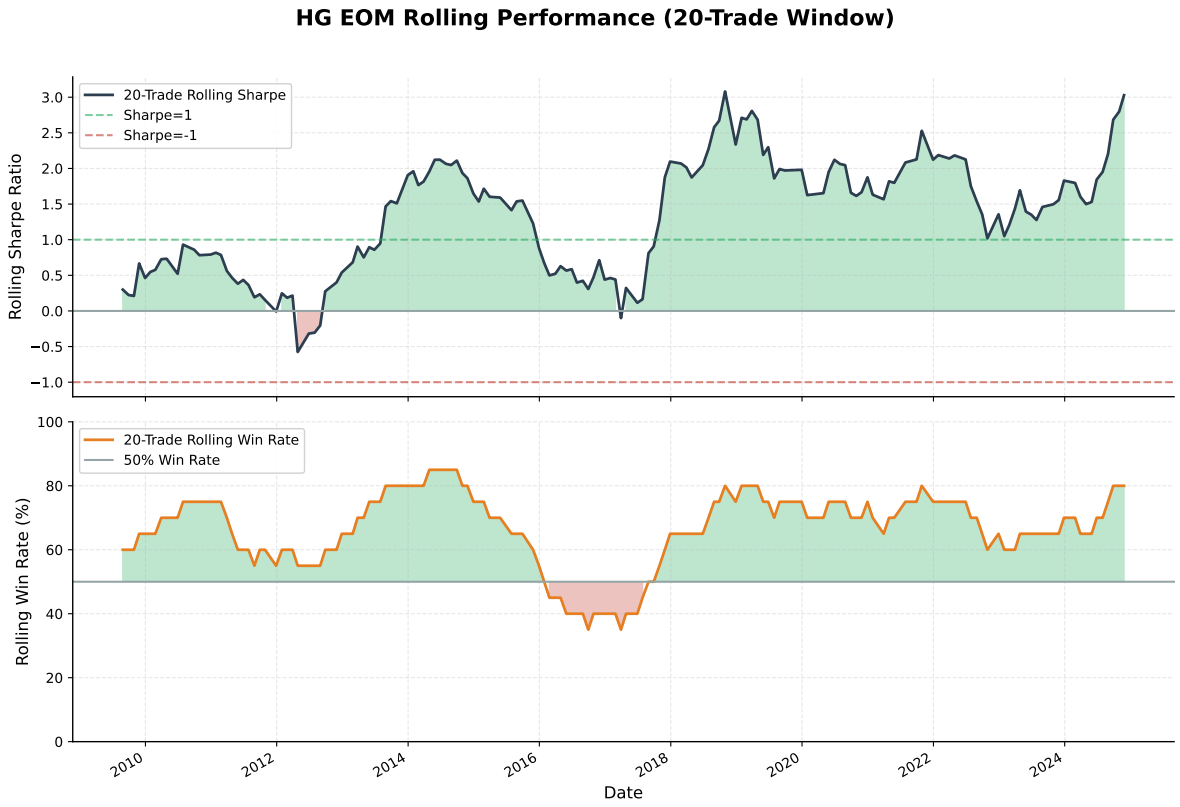

Figure 20: EOM rolling Sharpe ratio and win rate (20-trade window).

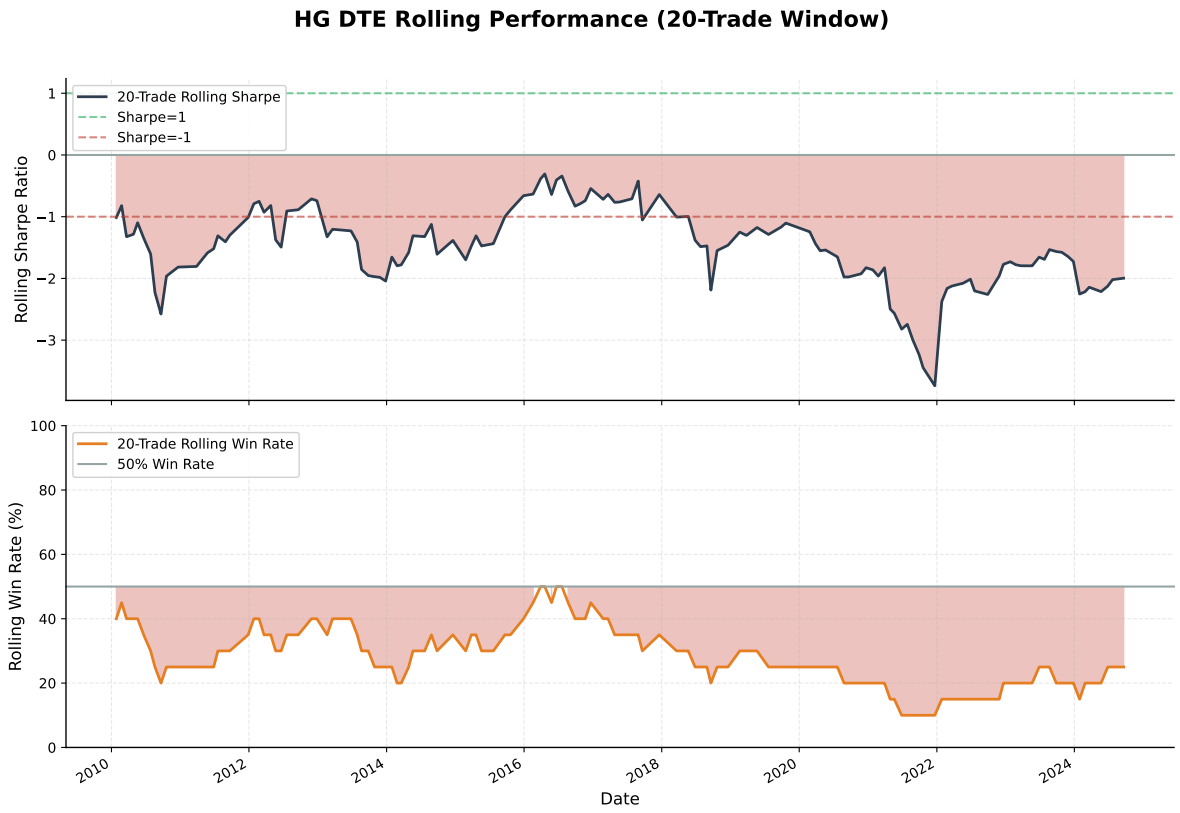

Figure 21: DTE rolling Sharpe ratio and win rate (20-trade window).

10.2 Cumulative Monthly P&L

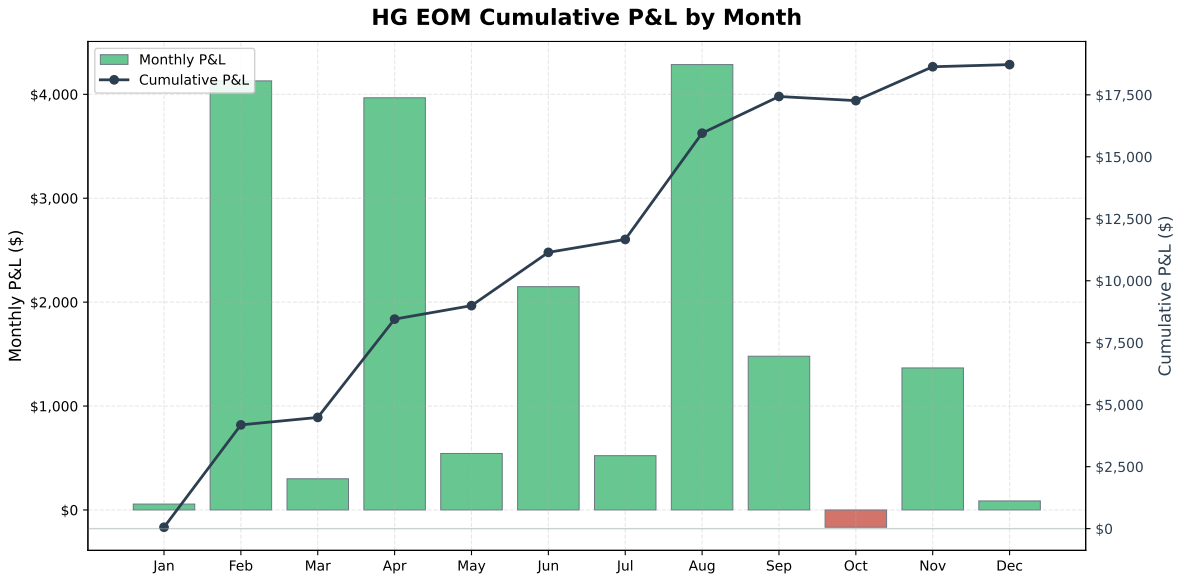

Figure 22: EOM monthly P&L breakdown with cumulative total.

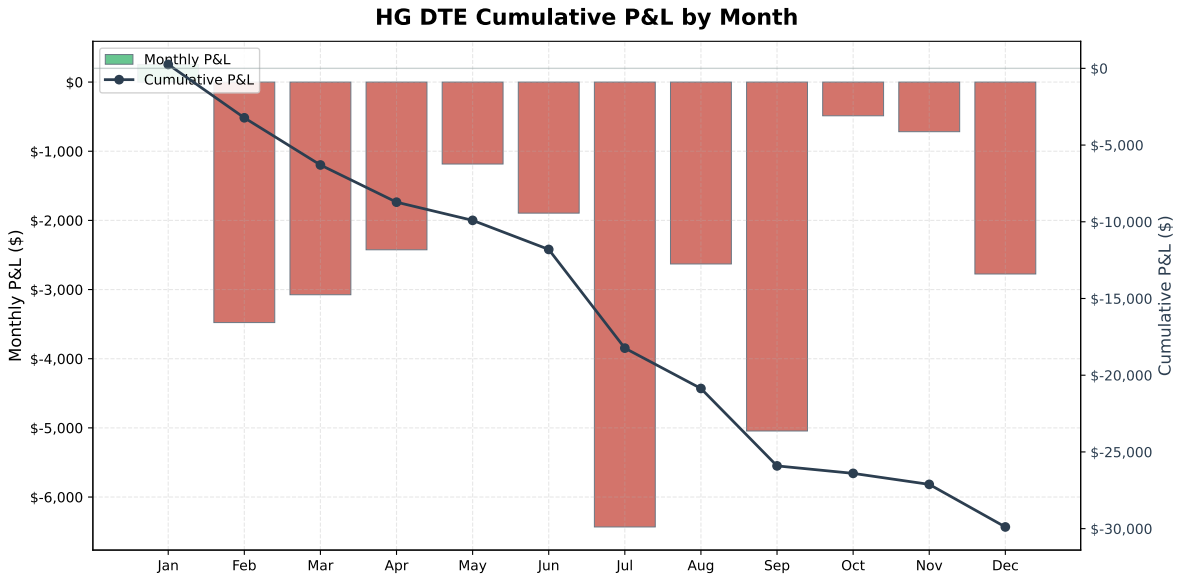

Figure 23: DTE monthly P&L breakdown with cumulative total.

11 Threats to Validity

11.1 Look-Ahead Bias

Mitigation: All signals use only data available at signal time. The backtester enforces a one-observation delay between signal and execution (no same-observation fills).

Residual risk: Execution prices are observation closes (bucket close / daily proxy) rather than bid/ask executable prices. This can overstate realizability in fast markets.

11.2 Transaction Cost Assumptions

Concern: Baseline costs may not reflect actual execution, especially during volatile periods.

Mitigation: Sensitivity analysis tests a wide range of cost assumptions. For HG, the EOM strategy remains profitable under a wide range of costs; the DTE strategy does not.

11.3 Limited Strategy Variants

Concern: Only two strategy variants (DTE, EOM) were tested. Results may reflect data mining if many strategies were tried.

Mitigation: Strategy selection was hypothesis-driven based on economic rationale, not curve-fitted to the data.

11.4 Single Commodity Focus

Concern: Results may not generalize to other commodities.

Mitigation: The pipeline architecture supports multi-commodity analysis. Future work should test strategies on a broader universe.

11.5 Survivorship Bias

Concern: Analysis includes only contracts that completed their lifecycle.

Assessment: Not applicable for futures (contracts expire per schedule, not delisted due to performance).

12 Conclusions and Recommendations

12.1 Summary of Findings

1. **Spread Dynamics:** HG calendar spreads exhibit systematic patterns related to contract lifecycle (DTE) and calendar effects (EOM)
2. **Seasonality:** Monthly patterns exist but require careful statistical treatment given sample size limitations
3. **Roll Behavior:** Volume share transition provides a reliable signal for roll timing
4. **Strategy Viability (HG):** EOM is profitable net of transaction costs in this sample; DTE is not (under this rule definition)

12.2 Strategy Viability Assessment

Based on the backtest results:

- **EOM Strategy:** Economically motivated by index rebalancing; positive Sharpe ratio with acceptable drawdowns
- **DTE Strategy:** Not profitable in this sample under the baseline rule; further work is needed to refine the hypothesis or the implementation
- **Combined:** Low correlation between strategies suggests diversification benefit

12.3 Recommended Next Steps

1. **Out-of-Sample Testing:** Reserve recent data for validation
2. **Multi-Commodity Extension:** Test on GC, CL, and other metals
3. **Parameter Sensitivity:** Explore DTE entry/exit thresholds
4. **Regime Analysis:** Condition strategies on volatility regime
5. **Live Paper Trading:** Forward test with simulated execution

A Parameter Reference

This appendix documents the configuration parameters used for all analyses in this report.

A.1 Pipeline Configuration

```
data_dir: /home/austinli/Dropbox/Future_project_1/data_parquet
research_dir: /home/austinli/Dropbox/Future_project_1/research_outputs
```

A.2 Backtest Configuration

```
Execution:
  slippage_ticks: 1
  commission_per_contract: 2.50
  tick_size: 0.0005
  tick_value: 12.50
  initial_capital: 100000

DTE strategy:
  entry: 5 < F1_dte_bdays <= 15
  exit:  F1_dte_bdays <= 5
  direction: long S1

EOM strategy:
  executed entry: EOM-3
  executed exit:  EOM-1
  direction: long S1
```

B Sample Trade Records

First 15 trades from the backtest trade log:

entry_date	exit_date	direction	entry_price	exit_price	pnl
2008-04-07	2008-04-28	1	-0.0285	-0.0465	-510.0000
2008-05-07	2008-05-21	1	-0.0195	0.0185	890.0000
2008-06-05	2008-06-26	1	-0.0240	0.0000	540.0000
2008-06-27	2008-07-29	1	0.0060	-0.0380	-1160.0000
2008-07-30	2008-08-27	1	-0.0535	-0.0460	127.5000
2008-09-05	2008-09-26	1	-0.0090	0.0020	215.0000
2008-09-29	2008-10-29	1	-0.0040	0.0285	752.5000
2008-10-30	2008-11-25	1	-0.0085	0.0040	252.5000
2008-11-27	2008-12-29	1	0.0110	0.0000	-335.0000
2009-02-04	2009-02-18	1	0.0130	-0.0045	-497.5000
2009-04-06	2009-04-21	1	0.0155	-0.0236	-1037.5000
2009-05-06	2009-05-20	1	-0.0090	-0.0040	65.0000
2009-06-05	2009-06-26	1	-0.0095	-0.0035	90.0000
2009-06-29	2009-07-29	1	0.0160	0.0035	-372.5000
2009-07-30	2009-08-27	1	0.0144	-0.0065	-582.5000

Table 8: Sample trade records showing entry/exit dates, direction, prices, and net P&L.

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D Methodology Notes

- **Exchange Time:** All timestamps are in US/Central (CME).
- **Trade Date Boundary:** 17:00 CT marks start of each trade date.

- **Contract Labels:** F1–F12 ranked strictly by expiry (not by volume).
- **Spread:** $S1 = F2 - F1$ in price units; normalized as $(F2 - F1)/F1$.
- **Transaction Costs:** Modeled per-leg per-side (4 fills per round trip).
- **Sharpe:** Annualized using equity-curve timestamp spacing (data-driven annualization factor).