UCD Michael Smurfit Graduate Business School

Group 37

Derivative Securities - FIN42020

Trimester 1 – Autumn - 2025

Submission date: 28 November 2025

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Assessment Submission Form

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Assessment Title:	Derivative Securities Group Project
Module Code:	FIN42020-Derivative Securities-2025/26 Autumn
Module Title:	Derivative Securities Group Project

Declaration of Authorship: *I/We declare that all materials included in this assessment is the end result of my/our own work and that due acknowledgement has been given in the bibliography and references to ALL sources be they printed, electronic or personal.*

Signed:

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Date: ______28NOV2025____________________

Notes:

1. A signed copy of this form must accompany all submissions for assessment. Where this is a group assessment, all group members must sign the form.
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INDIVIDUAL CONTRIBUTION

UCD DUBLIN UCD College of Business

Group Assessment: FIN42020-Derivative Securities Group Project

Individual Contribution of Each Group Member

A completed copy of this form should be included as an appendix in all group assessments submitted.

Student Name	**Please provide a detailed summary of your contribution to the completion of the group assessment.** This summary should include details of, for example, group meetings attended, research/reading conducted, writing and editing of sections of the report/presentation etc.	**% Contribution**
Etga Usta	- Data collection - Coding: Put – call parity - Writiting: Put – call parity	22.75%
Himanshu Ludhwani	- Data collection - Coding: Volatility Trade - Writing: Volatility Trade	22.75%
Jasveen Kaur	- Data collection - Writing: Put – Call Parity and Volatility trade (Supported)	9%
Mi Hoang Vu	- Data collection - Coding: Delta hedging (supported) - Writing: Executive summary, Implied Volatility, Delta hedging, Conclusion. - Construct and finalize report	22.75%
Shubh Goela	- Data collection - Coding: Implied Volatility, Volatility surfaces, Delta hedging, Volatility Trade - Writing: Implied Volatility (supported)	22.75%

THE NEW YORK STOCK EXCHANGE (NYSE)

Taiwan Semiconductor Manufacturing Co Ltd (TSM)

Closing price: $289.98

USD/EUR: 0.86

I. EXECUTIVE SUMMARY

The team uses options-based valuation techniques such as put-call parity, implied volatility estimation, volatility surface construction, delta-hedging simulations, and volatility trading strategies, this report examines Taiwan Semiconductor Manufacturing Company (TSMC). We process the data on Python based on this foundation of theory process and the support of AI generative model for debugging the code. The results show that there are often theoretical arbitrage opportunities, but the majority are too tiny to overcome obstacles in the real world. Significant skew dynamics are revealed by implied volatility patterns, with deep in-the-money call options generating erratic estimates because of no-arbitrage violations. Implied-volatility-based hedging performs better than historical-volatility hedging in volatile markets, according to delta-hedging simulations. Options were overpriced in relation to actual volatility, which led to a loss, according to a straddle-based volatility trade. All things considered, the analysis offers a thorough assessment of TSMC's option structures and market efficiency.

II. BUSINESS DESCRIPTION

One of the leading producers of semiconductors in the world, TSMC specializes in advanced wafer fabrication and offers specialized foundry services to a wide range of clients. The company creates and manufactures integrated circuits for consumer electronics, IoT devices, smartphones, automotive systems, and high-performance computing. Its operations, which include several sizable factories and international support offices, allow it to provide a wide range of superior semiconductor technologies in response to industry demand. The company's American Depositary Shares are listed on the New York Stock Exchange under the symbol TSM, and it is publicly traded on the Taiwan Stock Exchange under the ticker 2330.

Table 2.1: Share Statistics

Avg Vol (3 month)	13.31M
Avg Vol (10 day)	13.47M
Shares Outstanding	5.19B
Implied Shares Outstanding	5.19B
Float	24.17B
% Held by Insiders	0.04%
% Held by Institutions	16.28%

Shares Short (11/14/2025)	34.64M
Short Ratio (11/14/2025)	2.51
Short % of Float (11/14/2025)	0.67%
Short % of Shares Outstanding (11/14/2025)	0.67%
Shares Short (prior month 10/15/2025)	34.08M

Source: Yahoo Finance

III. PUT – CALL PARITY

To find if there are theoretical arbitrage opportunities, Put-Call Parity applied.

To make our model more realistic and to avoid flagging very small differences caused by market noise, we programmed in a "Tolerance" of $0.01. This represents a baseline for small transaction costs, like brokerage fees. For the "risk-free" interest rate, we chose the 1-Month U.S. Treasury Bill Rate (Market Yield, 2025).

Our model reveals put-call parity violations that create small, transaction-cost-sensitive arbitrage opportunities

For the 19th of September 2025, there is a 41 option level between 70 and 340 strike prices. Right side of the parity is greater than the 0.01 tolerance level in 24 of these levels and this provides an arbitrage chance by selling call option and buying put options. On the remaining 17 options selling put and stock to buy call option and lending at risk free rate provides profit.

Table 3.1: TSM Arbitrage Strategy for the Strike 260

19th September 2025 At the Money Option = 260	
Closing Price of the Stock: $264.87	**Arbitrage Strategy**: Sell put option and stock to buy Call option and lend strike value at Risk-Free Rate; the Net Cash Flow will be $0.883. Assumed brokerage fees cost is $0.01, our Initial profit will be $0.873.
Call Price is $13.35 / **Put Price** is $8.53	
Compounded risk-free rate is 0.4183	
Left Side of the Parity = $8.53 + $264.87	
Right Side of the Parity = $13.35 + $259.1670	

Source: Bloomberg and Team estimates

The market was not perfectly efficient during this period. However, we still need to evaluate real-world evaluations before trade.

On any given day, we didn't just find one or two mispriced options, but our model flagged a large portion of the options across a wide range of strike prices. However, it's vital to distinguish between this theoretical profit on a model and real-world situations. Many of these opportunities involve small potential profits that would likely be completely erased by real-world trading frictions. Such as:

Transaction Costs: Our $0.01 tolerance is just an assumption. Real brokerage commissions can be much higher and volatile.

The Bid-Ask Spread: Our model uses a single price, mid-price, which is the average of Ask and Bid prices. In a live trading scenario, it is more likely that we expect to buy at the higher "ask" price and sell at the lower "bid" price.

Execution Risk: It is the risk that in the time it takes for your order to reach the market and get executed, the price has already changed. Since arbitrage relies on capturing tiny price differences, even a very small change on any of the trades can be enough to make the entire strategy unprofitable.

IV. IMPLIED VOLATILITY

1. Methodology

Implied volatility (IV) represents the volatility parameter that makes the Black-Scholes-Merton option price equal to the observed market price of the option. Since the Black-Scholes formula cannot be algebraically inverted to solve volatility directly, numerical iterative methods are required.

The hedging framework follows the Black – Scholes (1973) structure. For each trading day t, the option delta is computed as

$$\Delta_{\text{call}}(t) = N(d_1(t))$$

where

$$d_1(t) = \frac{\ln\,(S_t/K) + (r - q + \frac{1}{2}\sigma_t^2)T_t}{\sigma_t\sqrt{T_t}}$$

and S_t is the spot price, K is the strike, r is the risk – free rate, q is dividend yield, σ_t is the daily volatility input and T_t is the time until maturity. For each contract, the volatility parameter σ is computed by:

$$\text{BS}(S, K, r, T, \sigma) = P_{\text{market}}$$

Where BS denotes the Black – Scholes theoretical price for calls or puts, S is the underlying price, K is the strike, r is the risk free rate and T is the time to maturity while P_{market} is the mid – quote (Hull, 2014). Where BS denotes the Black – Scholes theoretical price for calls or puts, S is the underlying price, K is the strike, r is the risk-free rate and T is the time to maturity while P_{market} is the market price (Hull, 2014). The dataset we use has two key inputs: the daily option chain of TSM (from which prices were used to calculate implied volatility) and the daily closing prices of TSM Equity (from which historical volatility is calculated as 22-day rolling window annualized standard deviation of daily log returns).

2. Observations

Deep In-the-Money Call Options Exhibit No-Arbitrage Violations and Near-Zero Vega, Producing Unstable Implied Volatility Estimates That Distort Strike Curves—While At-the-Money and Deep In-the-Money Put Options Yield Stable, Economically Valid Results Consistent with Equity Volatility Skew Patterns.

For the majority of strikes, the non–linear equation converges with unique implied volatility. However, several deep in – the – money calls produced economically invalid or unstable results.

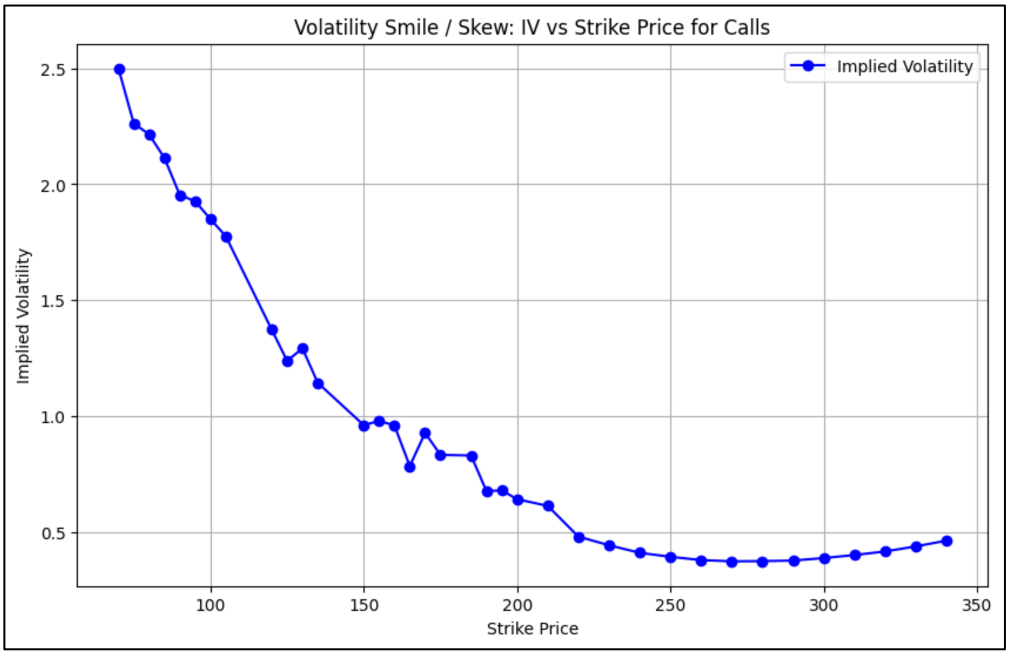
Table 4.1: TSM call option with strike K equals to 70

Deep in – the – money Call at K = 70	
Underlying price	$304.52
Strike	$70
Intrinsic value	$234.52
Market price	$234.40
Time value	$-0.22
Moneyness	$-4.35 (ITM)
Vega	~0

Source: Bloomberg and Team estimates

This option's market price is below intrinsic value, which violates the no – arbitrage lower bound. When evaluating the Black – Scholes price across volatilities from 0.01% to 500%, the theoretical price remains essentially flat around $234.59 - $235.87. The option Vega is effectively zero, implying that its value is almost entirely determined by the intrinsic value. Because the price is sensitive to volatility, no implied volatility can be recovered (Hull, 2014). This explains the extreme distortions observed at low strikes in the call implied volatility curve and the spikes in the call volatility surface. Such points will be treated as outliers and excluded from the implied volatility strike analysis.

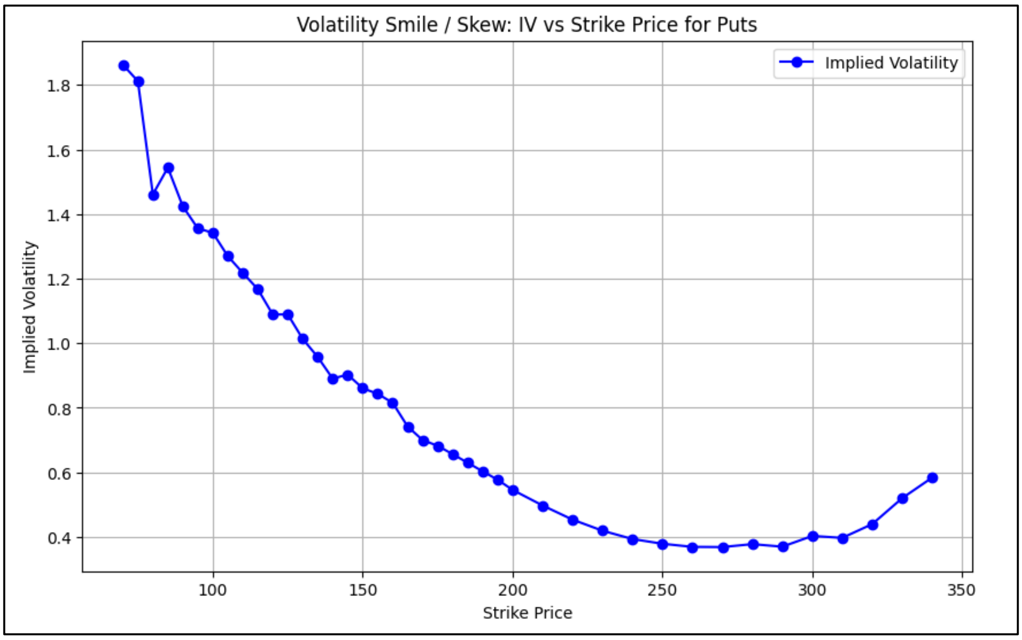
Figure 4.1: Implied Volatility vs Strike (Calls)



Source: Team estimates

The call implied volatility curve exhibits a steep downward trend: implied volatility exceeds 2.5 at very low strikes but declines steadily toward approximately 0.35 – 0.45 near at – the – money region. The large peaks at low strikes correspond to deep in – the – money calls such as the strike equals $70, where no arbitrage violations and near – zero Vega undermine the stability of the implied volatility estimate. After excluding these extreme points, the remaining call curve would display a classical equity – option skew pattern.

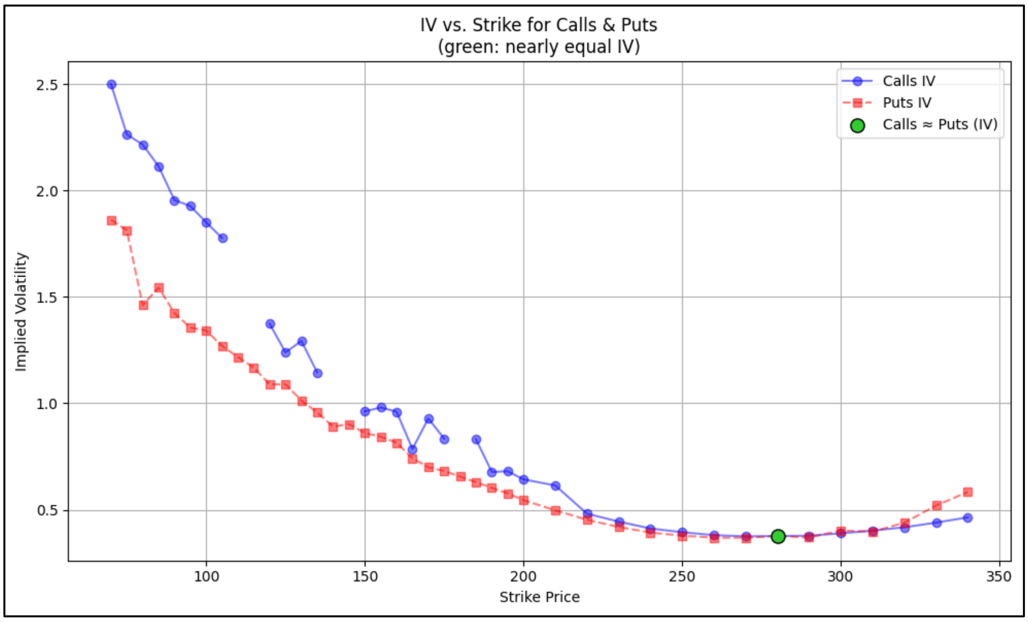
Figure 4.2: Implied Volatility vs Strike (Put)



Source: Team estimates

The put implied volatility curve also declines with strike but is smoother than the call curve. Implied volatility is highest for low – strike puts, reflecting crash – risk premium and then gradually decreases toward at –the – money levels before rising slightly at very high strike. Unlike deep in – the – money calls, deep in – the – money puts remain well – priced with nonzero Vega, which produces stable and economically meaningful implied volatility estimates.

Figure 4.3: Comparison of implied volatility calls and puts.



Source: Team estimates

As illustrated from the graph, the two curves converge closely at the at– the – money region where market efficiency and model assumptions are most valid. At low strikes, calls deviate significantly due to the deep in – the – money anomalies. At very high strikes, implied volatility puts tend to dominate, reflecting asymmetric demand for downside protection. These characteristics are consistent with the document on volatility skew in single - stock options (Rubinstein, 1994; Jackwerth, 2000).

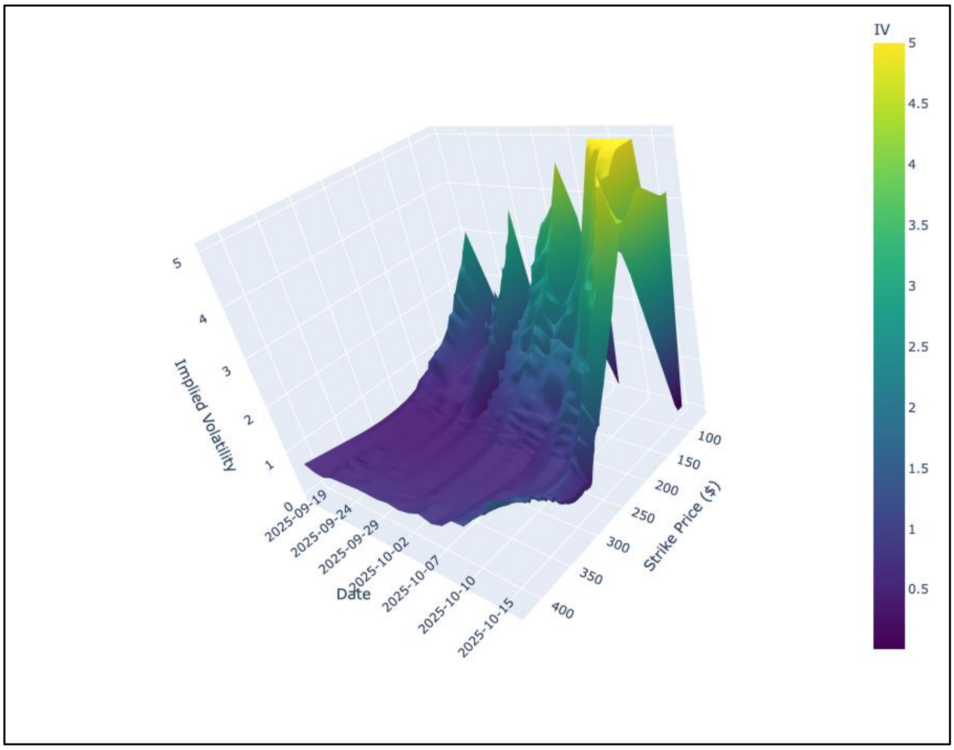
To understand more about the impact of time – series dynamics on implied volatility, our group has considered spot price evolution, at – the – money options and deep in – the – money and out – the – money options of TSM.

3. Volatility surfaces

Comparative visualization of call and put implied volatility across strike prices and time to maturity. Call surfaces exhibit pronounced instability at deep in-the-money strikes due to arbitrage violations and near-zero Vega, while put surfaces display smoother, economically interpretable behavior reflecting embedded crash premium. Surface convergence occurs near at-the-money strikes where put-call parity holds, with divergence emerging at extremes due to structural asymmetries in risk pricing.

To bring out a clearer view of how implied volatility varies jointly across strike and time, our group has conducted three – dimensional volatility surfaces.

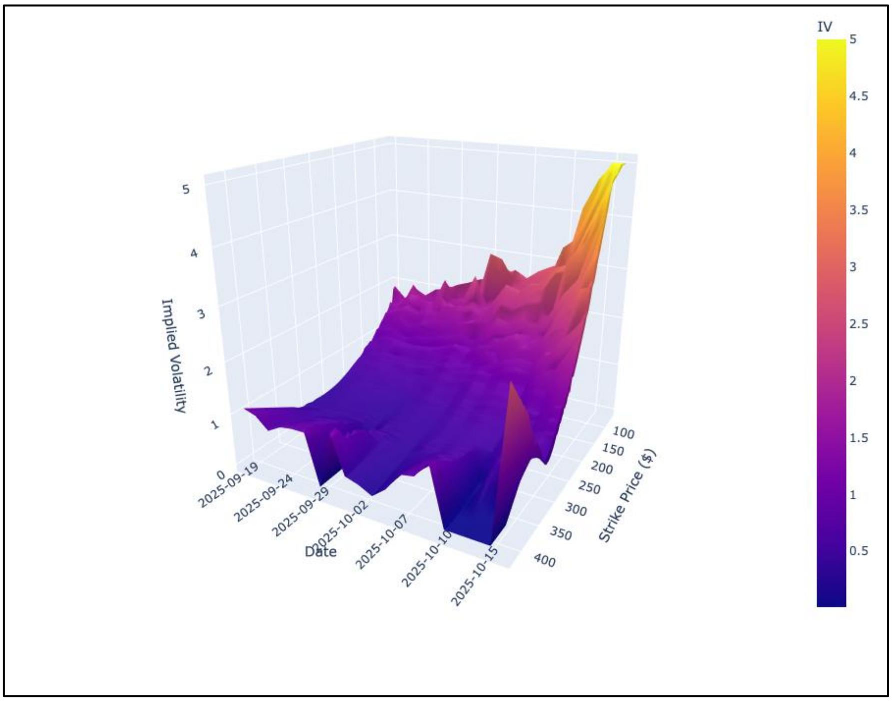
Figure 4.4: TSM call options volatility surfaces



Source: Team estimates

The call surface displays a relatively stable region near at– the – money strikes, surrounded by pronounced spikes at low – strike deep in – the – money positions. These spikes directly align with the diagnostic findings above, confirming that such options generate unstable and inflated implied volatility levels. The remaining surface displays a consistent downward skew along the strike dimension.

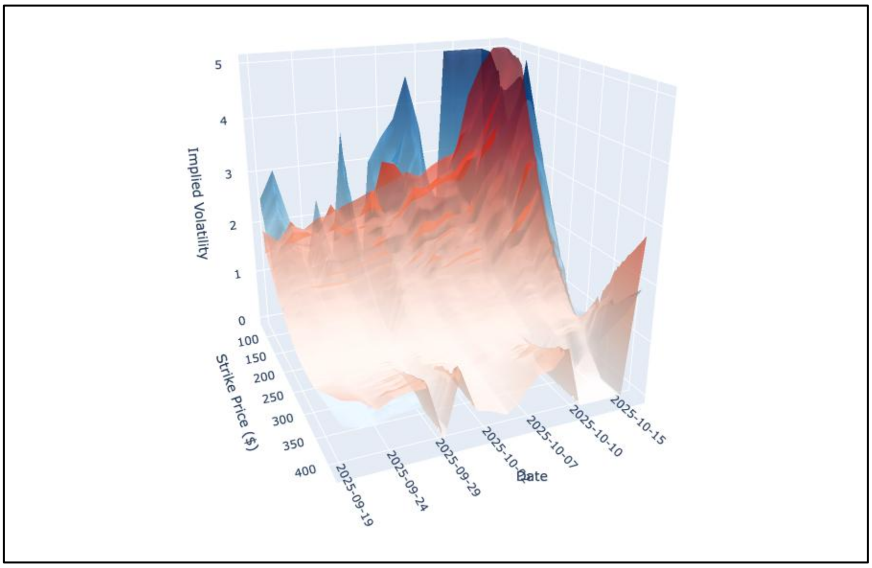
Figure 4.5: TSM puts options volatility surfaces



Source: Team estimates

The put surface is smoother and more economically interpretable. Low – strike puts exhibit high implied volatility due to embedded crash premium, while at – the – money and slightly out – the – money puts cluster around moderate implied volatility levels. The absence of arbitrage violations and greater pricing regularity in puts contributes to cleaner surface behavior.

Figure 4.6: TSM volatility surfaces (calls and puts)



Source: Team estimates

By overlaying two surfaces we can see their agreement near the at – the – money region where call and put prices converge under put – call parity. Divergence emerges at low strikes due to call anomalies and at high strikes where put implied volatility tends to exceed call implied volatility. This composite surface visualizes the full implied volatility landscape and reinforces the asymmetry of risk pricing across TSM options.

In conclusion, the analysis has shown a coherent and economically meaningful implied volatility structure for TSM options. Call and put implied volatility curves align closely around at – the – money strikes where pricing efficiency, nonzero Vega and put – call parity hold strongly. At extreme strikes, stark differences emerge. Deep in – the – money calls usually violate no arbitrage constraints and exhibit near – zero Vega, making implied volatility estimates unreliable and inflated. Puts, in contrast, demonstrate smoother behavior attributable to better – behaved pricing and structural role of put options in capturing downside – risk. Time – series plots further confirm that at – the – money options deliver stable implied volatility estimates while deep in – the – money contracts yield excessive volatility and noise. **The three – dimensions volatility surfaces firmly illustrated these insights: call surfaces show instability at low strikes while put surfaces retain more regular shapes.**

V. DELTA HEDGING

Implied-volatility-based hedging is more effective in dynamic markets because it responds immediately to changes in risk, whereas historical-volatility-based hedging tends to under-react and leaves residual exposure unhedged.

Simulation 1: Hedging with Daily Implied Volatility (Recommend)

Table 5.1: Summary of Simulation 1

Metric	Value
Option Type	CALL
Strike	$260.00
Position Size	–1 contract
Initial Premium	–$13.95
Final Hedge Position	1.0000 shares
Final Underlying Value	$295.08
Average Cost per Share	$280.62
Cumulative Realized P&L	$2.36
Unrealized P&L	$14.46
Total Trading Cashflow	$439.28
Reconciled P&L Check	–5.9035

Source: Team estimates

Implied - volatility hedge shows a portfolio that reacts quickly to movements in both the underlying price and market - implied risk.

The average cost of acquiring the final hedge position is $280.62, which is noticeably higher than the level observed in the historical – volatility hedge. The higher cost does not mean it is inefficient; it reflects a hedge that adjusts promptly as deltas rise in response to the underlying's upward trend. Because implied volatility incorporates current market expectations, the hedge is forced to buy shares earlier at higher prices, reducing the time during which the short call remains under – hedged. This behaviour is also visible in the unrealized P&L of $14.46, which is smaller than the hedge accumulated shares at higher and more realistic prices as the underlying appreciated. The larger total trading cashflow of $439.28 confirms that the implied volatility strategy required more frequent balancing. However, this activity is consistent with tighter risk control and a hedge that closely tracks the evolving risk profile of the option.

Simulation 2: Hedging with Daily Historical Volatility

Table 5.2: Summary of Simulation 2

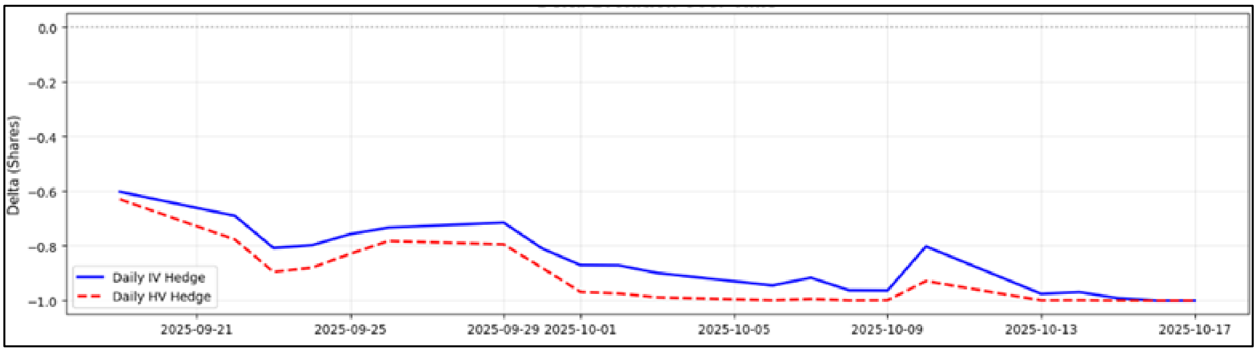
Metric	Value
Option Type	CALL
Strike	$260.00
Position Size	–1 contract
Initial Premium	–$13.95
Final Hedge Position	1.0000 shares
Final Underlying Value	$295.08
Average Cost per Share	$274.53
Cumulative Realized P&L	$1.55
Unrealized P&L	$20.55
Total Trading Cashflow	$379.29
Reconciled P&L Check	–0.6179

Source: Team estimates

Historical volatility hedge demonstrates the limitations of relying on backward – looking volatility estimates.

Because historical volatility adjusts slowly, deltas rise more gradually as the underlying trades higher. As a result, the hedge accumulates its final share position at a considerably lower average cost of $274.53. This number does not mean that the hedge in this case is effective but because it buy stocks later during the periods when the portfolio is still under – hedged. This delay leaves the short – call exposure unprotected throughout major upward price movements. The larger unrealized P&L of $20.55 further illustrates this point: the hedge appears more profitable only because it purchased shares at too low when the price is falling to neutralize risk when it needed most. Additionally, the smaller total trading cashflow of $379.29 reflects fewer hedge adjustments. However, in this specific scenario, fewer trades indicate slower responsiveness rather than greater efficiency.

Figure 5.1 – Delta Evolution (IV vs HV)

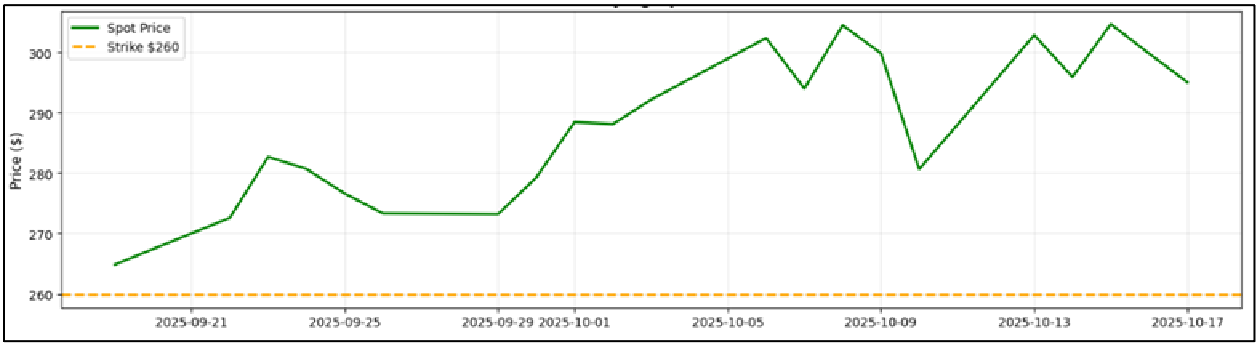


Source: Team estimates

Implied volatility delta dropped faster and stayed more negative than historical volatility delta, leading to systematic under – hedging.

As illustrated in the graph, the implied volatility delta declined more sharply than the historical volatility delta in the first two weeks. The steeper descent reflected the market's rising expected volatility. By October, implied volatility deltas were consistently more negative, closely tracking upward spot movements. The sudden implied volatility spoke around October 15th forced delta to nearly -1.0, showing the hedge's sensitivity to volatility shocks. During the critical period from October 9th to 15th, when spot rose close to $300, historical volatility deltas remained materially less negative then implied volatility deltas, leaving the hedge systematically under – hedged. This under – reaction maginified losses during strong directional moves.

Figure 5.2: Underlying spot price

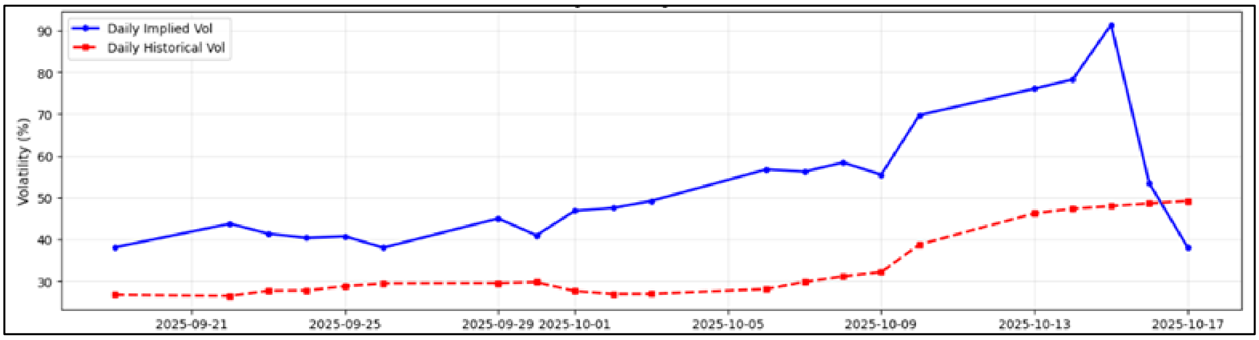


Source: Team estimates

Bullish move causes losses.

The underlying spot price graph has shown a clear upward trend from $265 to over $300. Such persistent bullish move is structurally unfavorable for a short – call position and has clearly explained why both hedges produce losses despite frequent – rebalancing.

Figure 5.3: Volatility Graph



Source: Team estimates

Implied volatility jumped sharply while historical volatility rose slowly, explaining why implied-volatility deltas reacted far more aggressively.

It can be seen that implied volatility reacted immediately to market developments, rose from 38% to peaked above 70 – 90%. historical volatility lagged behind, increased only slowly from 27% to about 50% by expiry. This divergence has obviously explained why implied volatility deltas respond sharply while historical volatility deltas remain subdued.

In conclusion, both hedges suffered losses because the underlying rallied strongly throughout the life of the option, pushing the call deep in the money. However, the implied volatility hedge delivered a smaller loss because it adjusted more rapidly to both the price trend and the volatility repricing observed in the options market. Historical volatility provided a smoother, more conservative volatility path, but its slow reaction caused systematic under – hedging during the most critical upward moves. **For clients, our team suggests that in fast – moving markets with significant volatility dynamics, hedging based on implied volatility provides more materially better protection and should be preferred for – risk sensitive or high – frequency hedging strategies.**

VI. VOLATILITY TRADE

In this part we trade according to volatility in the market for this we are comparing implied volatility (market's expectation) against historical volatility (realized past volatility) and implement a straddle strategy to profit from any mispricing, for this we do a strategy comparison first.

If implied volatility is larger than historical volatility, options are expensive, we SELL straddle (bet that realized volatility will be lower than implied). If implied volatility is smaller than historical volatility, options are cheap, we BUY straddle (bet that realized volatility will be higher than implied).

A straddle consists of: 1 ATM (at-the-money) call option, 1 ATM put option. Both with the same strike price and expiration date and strike selection, the strike price closest to the spot price on the trade date was chosen to ensure the straddle is ATM.

Data sources used for this consist of - Spot Price - Current stock price on September 19, 2025 , ATM Strike - Strike price closest to spot ,Call Premium - Mid price of ATM call option, Put Premium - Mid price of

ATM put option , Implied Volatilities - IV from both call and put options and Expiration Date - October 17, 2025 (28 days to expiration).

Volatility Analysis on 2025-09-19 the historical volatility (22-day) is 26.70% Implied Volatility (at – the - money): 38.08%, implied volatility – historical volatility spread is 11.39%. Since implied volatility is larger than historical volatility, options are EXPENSIVE which means SELL volatility.

Table 6.1: Volatility trade analysis

Metric	Value
Historic Volatility	26.7%
Implied Volatility [ATM]	38.08%
IV – HV [Spread]	11.39%

Source: Team estimates

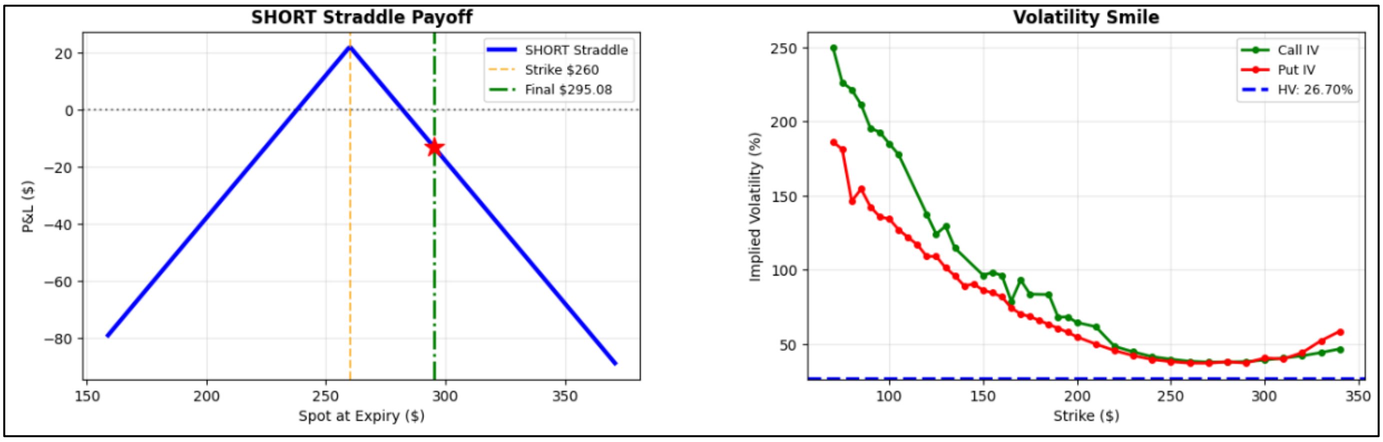
Table 6.2: Straddle construction

Metric	Value
Strike Price	$260
Call Premium	$13.95
Put Premium	$8.18
Total Premium	$22.13

Source: Team estimates

The options show significantly higher implied volatility on calls (99.74%) compared to puts (82.98%), indicating stronger demand or perceived upside risk. Calls are priced $5.78 higher than puts, reflecting this volatility skew. Based on current premiums, the estimated breakeven range is $237.87 on the downside and $282.13 on the upside, defining the price levels at which the position begins to show profit.

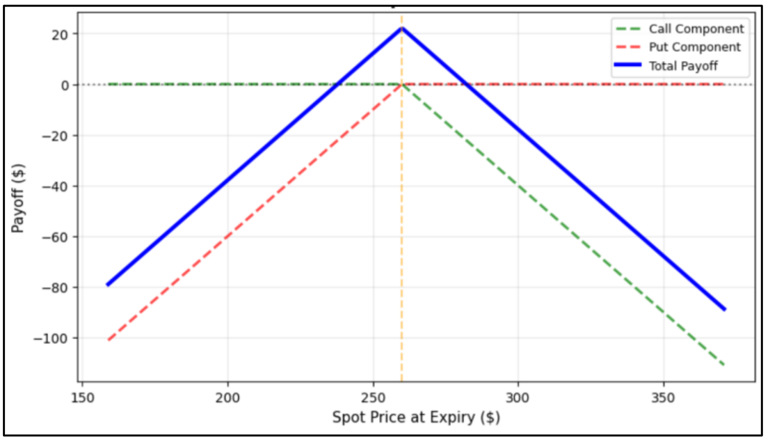
Figure 6.1: Short Straddle Payoff and Implied Volatility Smile



Source: Team estimates

The above graph shows the payoff at the time of expiry and along with that Call IV and Put IV. The volatility smile is a U-shaped pattern that appears in the above graph as we have plotted implied volatility against strike prices for options with the same expiration date.

Figure 6.2: Straddle component breakdown



Source: Team estimates

Table 6.3: Payout at expiry

Metric	Value
Final Spot Price	$295.08
Total Final P&L	-$12.95
Status	LOSS

Source: Team estimates

The Graph above represents long straddle options strategy, where you simultaneously buy a call (green dashed line) and put (red dashed line) at the same $250 strike price. The blue line shows the combined payoff, forming a V-shape with the vertex at $250 where maximum loss occurs (approximately $200 in total premiums paid). The strategy profits when the stock moves significantly in either direction.

VII. CONCLUSION

The analysis shows that although TSMC options exhibit theoretical arbitrage opportunities, exploitability is severely limited by practical constraints. With the exception of distortions brought on by deep in-the-money call mispricing, implied volatility structures exhibit typical equity-option behaviors. Implied volatility provides better risk responsiveness than historical measures, according to dynamic hedging results. The impact of implied–realized volatility divergence on strategy profitability is further demonstrated by the volatility trade. Overall, the project emphasizes how crucial it is to take volatility dynamics, market microstructure, and hedging responsiveness into account when assessing option-based strategies for TSMC.

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APPENDIX A: Group's work: Python Code File Link:

https://github.com/shubhgoela/Derivative-Securities

APPENDIX B: Group's work: 3D Graphs hosted on Cloud

(Since hosted on github – this might not work)

https://shubhgoela.github.io/Derivative-Securities/index.html

APPENDIX C: DAILY DELTA-HEDGING PATH (IMPLIED VOLATILITY SIMULATION)

No.	Date	Days to Expiry	Spot Price	Volatility	Option_Value	Delta	Position_Delta	Delta_Change	Required_Hedge	Hedge_Position	Shares_Traded	Trade_Price	Avg_Cost_per_Share	Value_of_Underlying	Cash_Flow	Realized_PnL_Today	Unrealized_PnL	Cum_Realized_PnL
0	2025-09-19	28.0	264.87	0.380826	13.950000	0.598347	-0.598347	0.598347	0.598347	0.598347	0.598347	264.87	264.870000	158.484126	158.484126	0.000000	0.000000	0.000000
1	2025-09-22	25.0	272.63	0.457595	20.324997	0.681375	-0.681375	0.083028	0.681375	0.681375	0.083028	272.63	265.815589	185.763353	22.636055	0.000000	4.643171	0.000000
2	2025-09-23	24.0	282.71	0.421624	26.750000	0.800829	-0.800829	0.119453	0.800829	0.800829	0.119453	282.71	268.335596	226.402272	33.770656	0.000000	11.511435	0.000000
3	2025-09-24	23.0	280.71	0.425723	25.050003	0.784140	-0.784140	-0.016689	0.784140	0.784140	-0.016689	280.71	268.335596	220.115959	4.684655	0.206511	9.703266	0.206511

4	2025-09-25	22.0	276.66	0.410181	21.400002	0.752800	-0.752800	-0.031340	0.752800	0.752800	-0.031340	276.66	268.335596	208.269534	8.670658	0.260891	6.266608	0.467402
5	2025-09-26	21.0	273.36	0.387331	18.250000	0.726699	-0.726699	-0.026100	0.726699	0.726699	-0.026100	273.36	268.335596	198.650508	7.134788	0.131139	3.651231	0.598541
6	2025-09-29	18.0	273.23	0.480608	19.400002	0.702311	-0.702311	-0.024388	0.702311	0.702311	-0.024388	273.23	268.335596	191.892440	6.663597	0.119366	3.437394	0.717907
7	2025-09-30	17.0	279.29	0.414750	22.450005	0.804640	-0.804640	0.102329	0.804640	0.804640	0.102329	279.29	269.728707	224.727895	28.579450	0.000000	7.693399	0.717907
8	2025-10-01	16.0	288.47	0.526714	31.525002	0.843145	-0.843145	0.038505	0.843145	0.843145	0.038505	288.47	270.584586	243.221968	11.107478	0.000000	15.079993	0.717907
9	2025-10-02	15.0	288.11	0.569499	31.574997	0.830466	-0.830466	-0.012679	0.830466	0.830466	-0.012679	288.11	270.584586	239.265494	3.652942	0.222204	14.554257	0.940111

10	2025-10-03	14.0	292.19	0.617634	35.375000	0.849262	-0.849262	0.018796	0.849262	0.849262	0.018796	292.19	271.062769	248.145899	5.492104	0.000000	17.942557	0.940111
11	2025-10-06	11.0	302.40	0.726788	44.575005	0.897204	-0.897204	0.047941	0.897204	0.897204	0.047941	302.40	272.737251	271.314352	14.497488	0.000000	26.613523	0.940111
12	2025-10-07	10.0	294.03	0.674188	36.299995	0.877781	-0.877781	-0.019423	0.877781	0.877781	-0.019423	294.03	272.737251	258.093814	5.710945	0.413569	18.690361	1.353680
13	2025-10-08	9.0	304.52	0.790288	46.349998	0.909877	-0.909877	0.032096	0.909877	0.909877	0.032096	304.52	273.858393	277.075623	9.773891	0.000000	27.898279	1.353680
14	2025-10-09	8.0	299.88	0.706407	41.175003	0.922400	-0.922400	0.012524	0.922400	0.922400	0.012524	299.88	274.211695	276.609390	3.755595	0.000000	23.676451	1.353680
15	2025-10-10	7.0	280.66	0.833461	25.500000	0.765645	-0.765645	-0.156755	0.765645	0.765645	-0.156755	280.66	274.211695	214.886056	43.994802	1.010803	4.937115	2.364483

16	2025-10-13	4.0	302.89	1.100282	44.349998	0.917015	-0.917015	0.151370	0.917015	0.917015	0.151370	302.89	278.945564	277.754761	45.848406	0.000000	21.957414	2.364483
17	2025-10-14	3.0	295.94	1.056765	37.074997	0.919438	-0.919438	0.002422	0.919438	0.919438	0.002422	295.94	278.903399	272.098399	0.716895	0.000000	15.584158	2.364483
18	2025-10-15	2.0	304.71	1.550846	45.974998	0.925156	-0.925156	0.005718	0.925156	0.925156	0.005718	304.71	279.149313	281.904327	1.742459	0.000000	23.647627	2.364483
19	2025-10-16	1.0	299.84	1.286703	39.974998	0.984259	-0.984259	0.059102	0.984259	0.984259	0.059102	299.84	280.391740	295.120079	17.721263	0.000000	19.142116	2.364483
20	2025-10-17	0.0	295.08	0.010000	36.675003	1.000000	-1.000000	0.015741	1.000000	1.000000	0.015741	295.08	280.622954	295.080000	4.644992	0.000000	14.457046	2.364483

APPENDIX D: DAILY DELTA-HEDGING PATH (HISTORICAL VOLATILITY SIMULATION)

	Date	Days_to_Expiry	Spot_Price	Volatility	Option_Value	Delta	Position_Delta	Delta_Change	Required_Hedge	Hedge_Position	Shares_Traded	Trade_Price	Avg_Cost_per_Share	Value_of_Underlying	Cash_Flow	Realized_PnL_Today	Unrealized_PnL	Cum_Realized_PnL
0	2025-09-19	28.0	264.87	0.265688	13.950000	0.625035	-0.625035	0.625035	0.625035	0.625035	0.625035	264.87	264.870000	165.552993	165.552993	0.000000	0.000000	0.000000
1	2025-09-22	25.0	272.63	0.262730	20.324997	0.773973	-0.773973	0.148939	0.773973	0.773973	0.148939	272.63	266.363285	211.083882	40.605119	0.000000	4.850271	0.000000
2	2025-09-23	24.0	282.71	0.274716	26.750000	0.894004	-0.894004	0.120031	0.894004	0.894004	0.120031	282.71	268.580330	252.743978	33.933943	0.000000	12.651923	0.000000
3	2025-09-24	23.0	280.71	0.275329	25.050003	0.878496	-0.878496	-0.015508	0.878496	0.878496	-0.015508	280.71	268.580330	246.602654	4.353315	0.188456	10.675459	0.188456
4	2025-09-25	22.0	276.66	0.285856	21.400002	0.827285	-0.827285	-0.051211	0.827285	0.827285	-0.051211	276.66	268.580330	228.876583	14.168161	0.414914	6.702636	0.603369

5	2025-09-26	21.0	273.36	0.292271	18.250000	0.780123	-0.780123	-0.047162	0.780123	0.780123	-0.047162	273.36	268.558030	213.254315	12.892229	0.226471	3.746125	0.829840
6	2025-09-29	18.0	273.23	0.292874	19.400002	0.792963	-0.792963	0.012840	0.792963	0.792963	0.012840	273.23	268.633681	216.661200	3.508301	0.000000	3.644709	0.829840
7	2025-09-30	17.0	279.29	0.295236	22.450005	0.879919	-0.879919	0.086956	0.879919	0.879919	0.086956	279.29	269.686770	245.752537	24.285984	0.000000	8.450063	0.829840
8	2025-10-01	16.0	288.47	0.272896	31.525002	0.968763	-0.968763	0.088844	0.968763	0.968763	0.088844	288.47	271.409360	279.459085	25.628892	0.000000	16.527719	0.829840
9	2025-10-02	15.0	288.11	0.265934	31.574997	0.974175	-0.974175	0.005412	0.974175	0.974175	0.005412	288.11	271.502141	280.669606	1.559276	0.000000	16.178964	0.829840
10	2025-10-03	14.0	292.19	0.266070	35.375000	0.988479	-0.988479	0.014304	0.988479	0.988479	0.014304	292.19	271.801511	288.823753	4.179512	0.000000	20.153598	0.829840
11	2025-10-06	11.0	302.40	0.277455	44.575005	0.998900	-0.998900	0.010421	0.998900	0.998900	0.010421	302.40	272.120734	302.067489	3.151363	0.000000	30.245972	0.829840

12	2025-10-07	10.0	294.03	0.295486	36.299995	0.994381	-0.994381	-0.004520	0.994381	0.994381	-0.004520	294.03	272.120734	292.377798	1.328895	0.099021	21.786154	0.928861
13	2025-10-08	9.0	304.52	0.308138	46.349998	0.999231	-0.999231	0.004850	0.999231	0.999231	0.004850	304.52	272.278002	304.285869	1.477017	0.000000	32.217209	0.928861
14	2025-10-09	8.0	299.88	0.318569	41.175003	0.998642	-0.998642	-0.000589	0.998642	0.998642	-0.000589	299.88	272.278002	299.472894	0.176542	0.016250	27.564527	0.945111
15	2025-10-10	7.0	280.66	0.389586	25.500000	0.926935	-0.926935	-0.071708	0.926935	0.926935	-0.071708	280.66	272.278002	260.153507	20.125480	0.601054	7.769566	1.546164
16	2025-10-13	4.0	302.89	0.459030	44.349998	0.999201	-0.999201	0.072266	0.999201	0.999201	0.072266	302.89	274.491986	302.648007	21.888741	0.000000	28.375325	1.546164
17	2025-10-14	3.0	295.94	0.470167	37.074997	0.998812	-0.998812	-0.000389	0.998812	0.998812	-0.000389	295.94	274.491986	295.588353	0.115208	0.008350	21.422528	1.554514
18	2025-10-15	2.0	304.71	0.476683	45.974998	0.999931	-0.999931	0.001119	0.999931	0.999931	0.001119	304.71	274.525814	304.689020	0.341088	0.000000	30.182107	1.554514

19	2025-10-16	1.0	299.84	0.482908	39.974998	0.999967	-0.999967	0.000036	0.999967	0.999967	0.000036	299.84	274.526725	299.830140	0.010785	0.000000	25.312443	1.554514
20	2025-10-17	0.0	295.08	0.488618	36.675003	1.000000	-1.000000	0.000033	1.000000	1.000000	0.000033	295.08	274.527401	295.080000	0.009703	0.000000	20.552599	1.554514