Dynamic Skew™ Algo

For Vela's Metro trading platform
Version 3.77 (07-22-2019)

Introduction By Developer

The volatility curve is one of the most critical components of any options trading operation. It has a direct and immediate effect on options pricing, yet is the only options pricing model input that is not clearly defined and that is constantly fluctuating. Academic research suggests that complex volatility curves result from price trajectories that may be unit root processes or jump processes. Indeed, equity options traded in American markets did not show "volatility smiles" until *after* the Crash of 1987 when investors made substantial reassessments on the probabilities of extreme events. This implies that volatility curves are a constantly evolving emergent property due to the realtime consensus of various open-ended risks (both preexisting and those newly identified) to the underlying.

The Dynamic Skew™ tool is a cutting-edge algorithm for Vela's Metro platform and is designed to help relieve the burden of setting and maintaining vol curves. By automating this process in a robust and quantitative manner, the options trader or market maker is freed to focus more on the trading and high-level strategy. The Dynamic Skew algo alleviates nagging doubts on the validity of perceived edge, allowing the trader to make consistent, quick, and confident execution decisions. Feedback from options traders using the algo suggests that it is "game changing" and has quickly become an irreplaceable component. The algo exposes fleeting vol trading opportunities that previously could not be realized. Robust market data handling and modeling logic provide superior vol curves during volatile conditions. This allows the trader to focus on opportunities with substantially less vol risk than if constant manual updates were required.

-Kevin Reeves (kevin@axonetric.com)
Axonetric LLC, Senior quantitative algorithmic trading engineer

Testimonials

"The groundbreaking Dynamic Skew algo (DSA) is a fully automated, intelligently designed, indispensable tool for today's unforgiving, cutthroat, algo-driven trading environment. Reliable, fast and exceptionally accurate, the DSA allows me to trade with clarity, conviction, and confidence.

My vol curves and wing slopes have never looked better or more precise. My theoreticals on my Trade Sheets are always spot on. And I never get 'picked off' on sudden moves in IV or skew anymore. The DSA performs remarkably well during busy volatile market environments. No more looking at a 'sea of red' on my Trade Sheets and trying to figure out which strike is the one that's off. I see every isolated pricing anomaly immediately with consistently accurate levels of theoretical edge. And best of all, I never have to manually adjust any vol curves or term structure slope during a busy trading session.

In retrospect, I feel I was simply wasting valuable time and energy manually adjusting and recalibrating my vol curves and Trade Sheets all day long. The Dynamic Skew algo now handles this task faster and more accurately than is humanly possible. The DSA gives me the complete freedom to solely concentrate on the most important tasks—position risk management and opportunistic trading."
-Rich D., 25+ years Independent Options Trader *(also beta tester & collaborator)*

"We're very happy with the Dynamic Skew Algorithm and consider it an all-in-one tool for auto-fitting and tweaking the theoretical price of option market skews of all types. We use the DSA to smoothly fine tune the fitting process for over 40 expirations at once, ranging from very tight near-term options to wide markets two years out.

Configuring the various settings is relatively intuitive and offers a satisfying balance of precision and flexibility. Kevin and his team are consistently available to help diagnose, explain, and remedy any issues related to the algo—going above and beyond to ensure customer satisfaction."

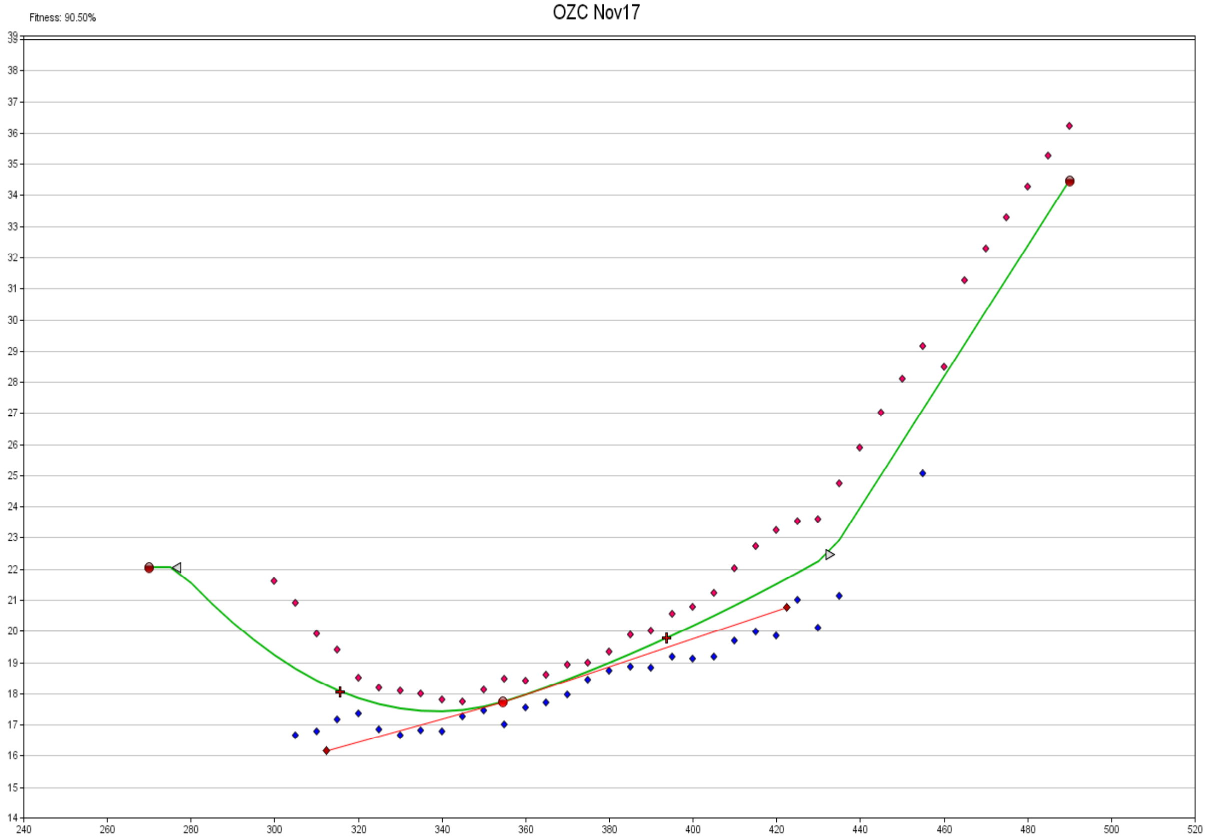
-US Equity Index Options Trading Desk

"The Dynamic Skew algo has become an extremely valuable tool in our trading operations."

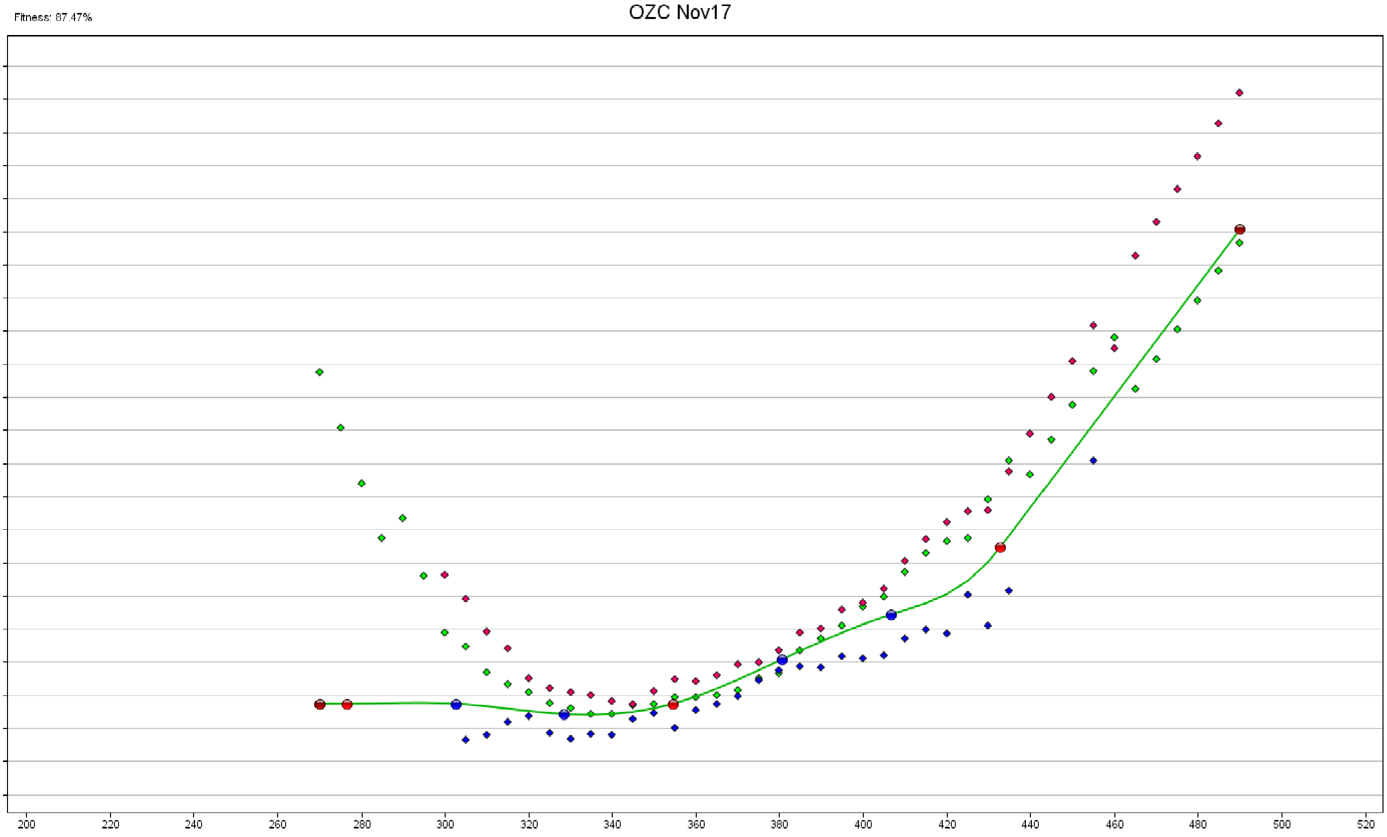
-Crude Oil Options Trading Desk

Visual Comparisons

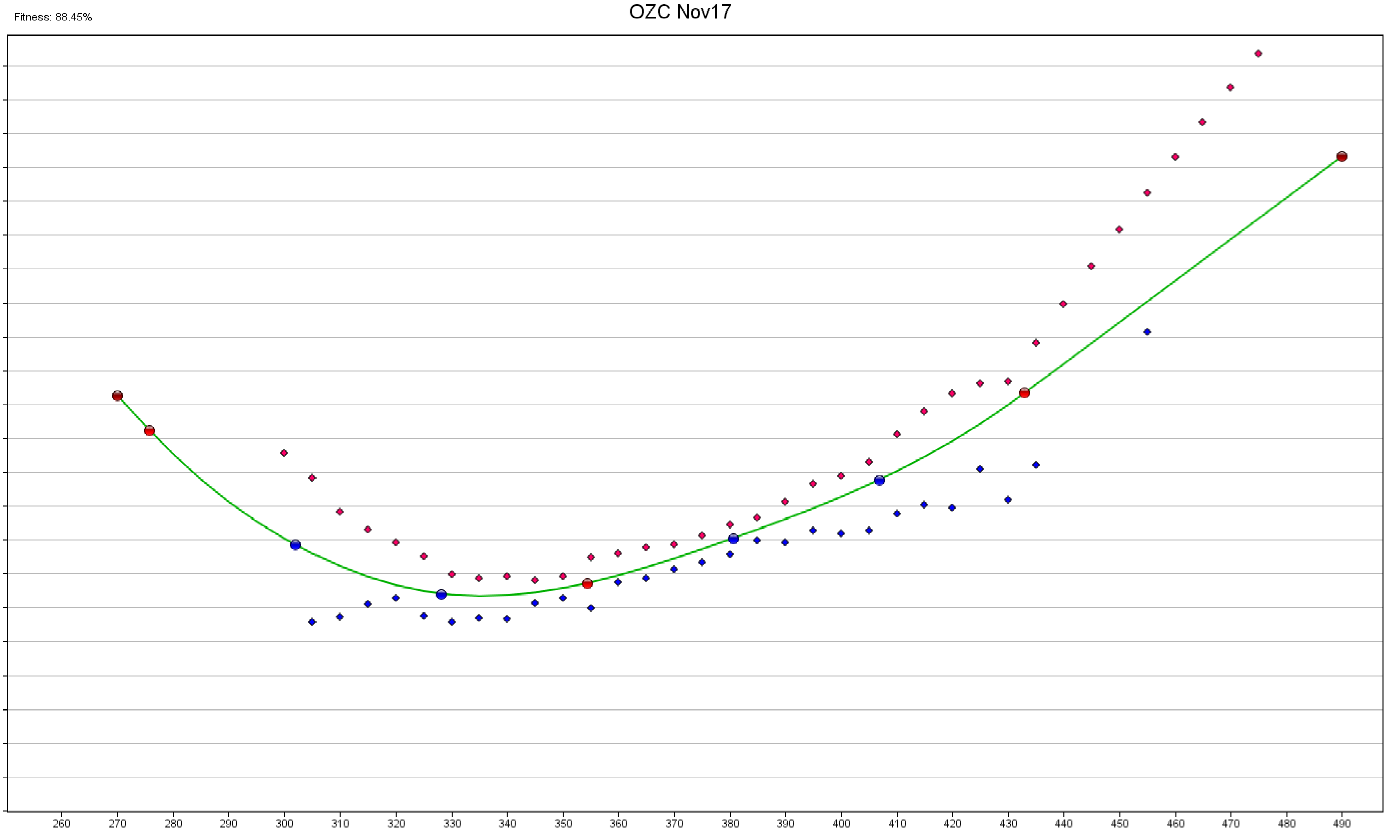
The screenshots below show side-by-side comparisons of various possible vol curve modeling approaches in the November 2017 corn options. The screenshots were taken within minutes of each other during an evening session so they are all comparable. It is the opinion of the author, and seconded by traders using the algo, that Dynamic Skew provides the superior performance across the board.



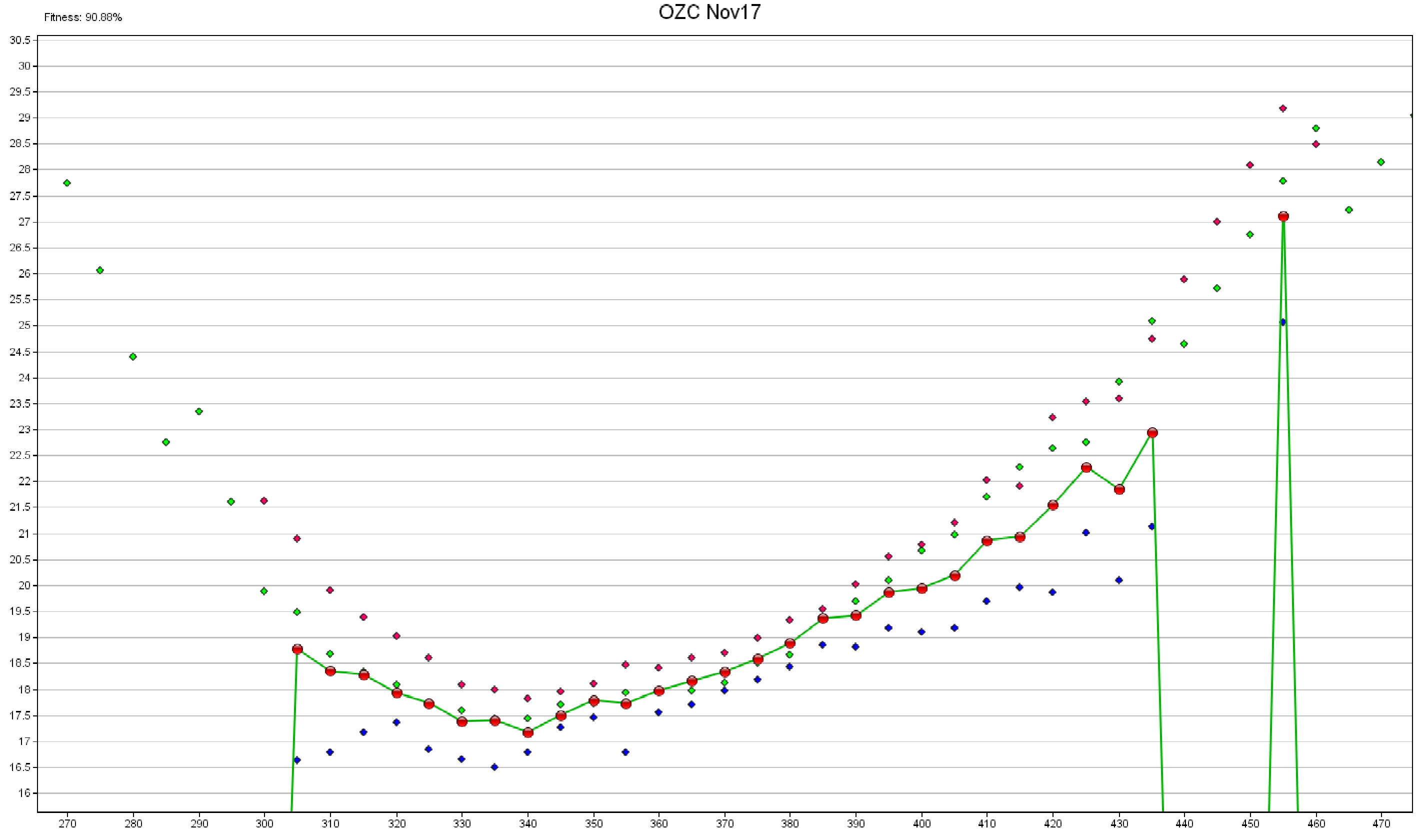
Metro Vol Curve: "Smoothed Two-Sided" – Implied Vol Fit



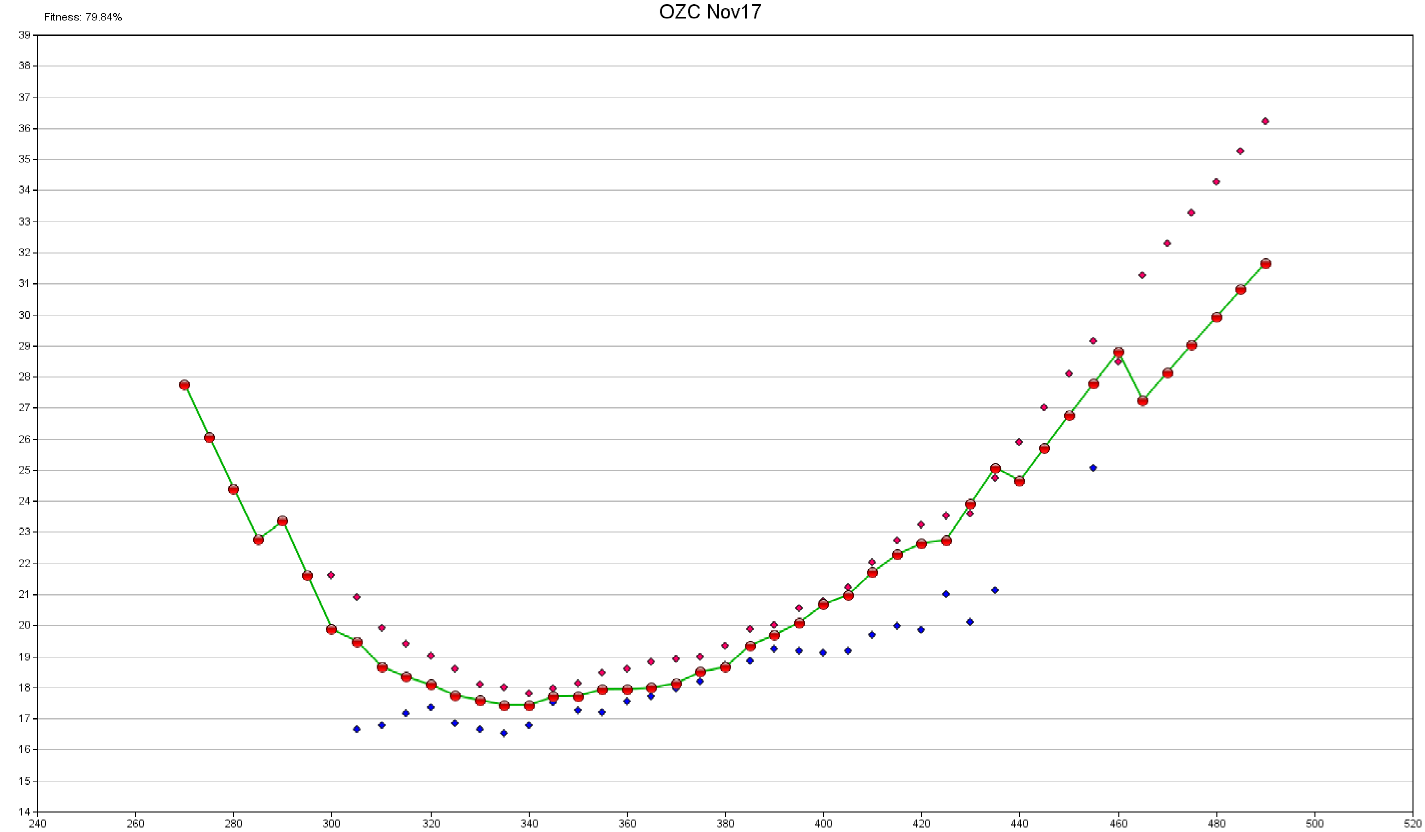
Metro Vol Curve: "Flexible Spline" – Implied Vol Fit



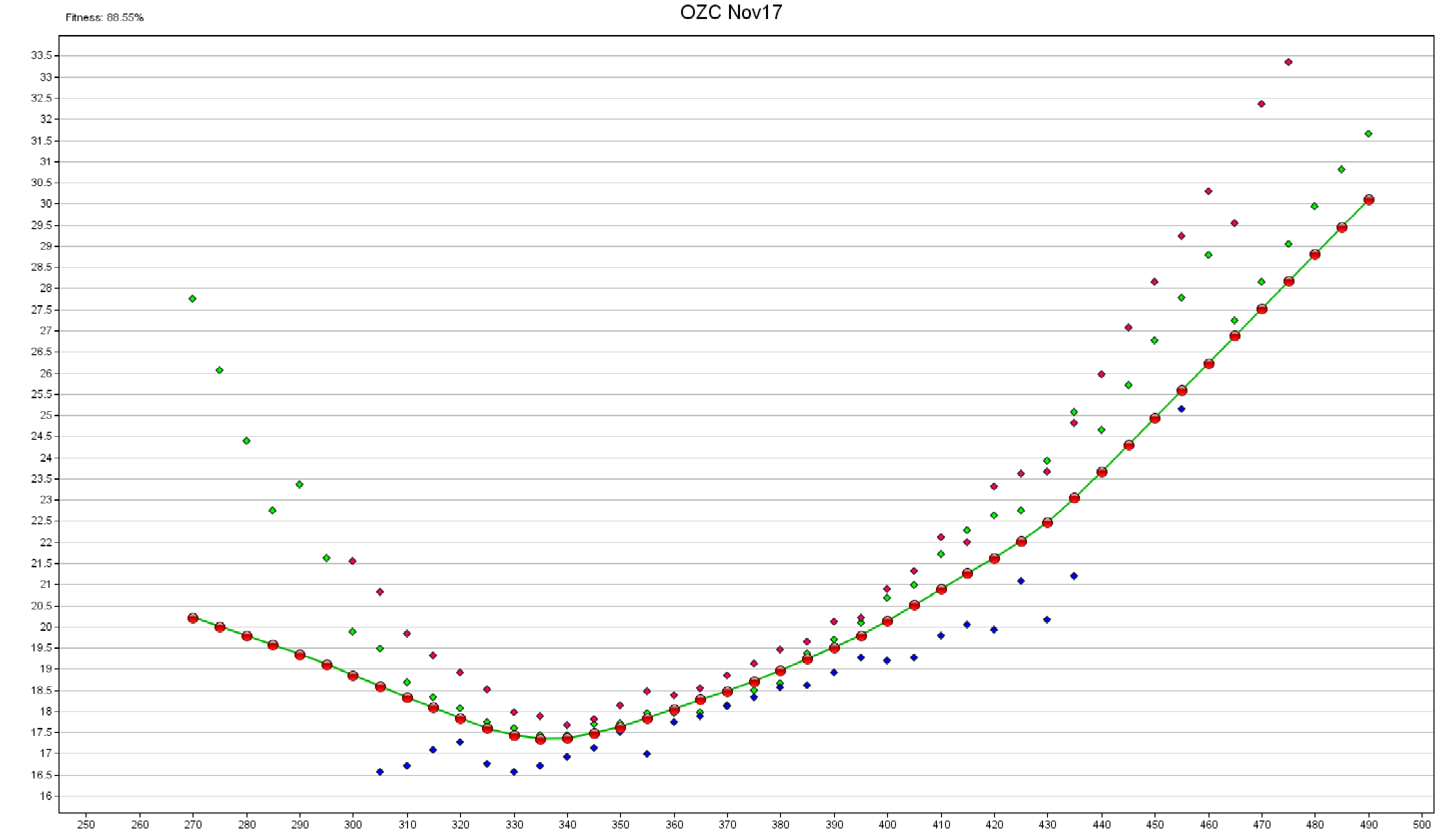
Metro Vol Curve: "Flexible Spline" – Manual Fit (trader dragging control points)



Metro Vol Curve: “Assigned” – Implied Vol Fit



Metro Vol Curve: “Assigned” – Latest Settlement Fit



Metro Vol Curve: “Assigned” – Dynamic Skew Fully Automated Realtime Fit

Features & Benefits

- Fully automates the management and maintenance of volatility curves across all actively quoted expirations with unsurpassed precision and accuracy. This eliminates the painful task of manual adjustments throughout the day.
- Generates near perfect “fair value” implied volatility curves with customizable levels of smoothness and outlier removal. These curves are unbiased and reflect the collective opinion of the marketplace. New curves are published at a user-defined frequency that can be as often as once per second.
- Compatible with both fixed and floating skew types. For the floating skew type, the Vol Slide’s path midpoint is recalibrated with every curve update. The Assigned curve type allows for maximum modeling resolution.
- Unique “multi-skew risk” functionality that enables the user to accurately track position risk with one skew type, while simultaneously trading and quoting off another.

- Fully configurable with numerous options to match the product dynamics, market conditions, and trader preferences:
    - Configurable outlier removal and curve smoothing techniques avoid over-fitting and allow excellent curve generalization.
    - Configurable time averaging and "curve stabilization" features allow better evolution of the vol curve over time. The Dynamic Skew algo can resist overreactions by filtering out high-frequency IV noise.
    - Two different wing treatment modes. One mode uses a robust and automatically determined linear slope ("auto-sloping"). The second mode allows a horizontal extension past the most extreme two-sided markets ("tabletopping") that is more suitable for near-expiration options.
    - Various market data filtering options allow the algo to exclude noisy input based on book liquidity and spread width.
- Advanced tiered logic allows accurate curve reconstruction and publication during liquidity crises, even with potentially wide or missing markets.
- Includes an informative grid report that tracks significant IV data for each expiration driven by the Dynamic Skew algo. This grid exposes vol trading opportunities with objective precision.
- Perfect integration with our new complementary **"Vol Levels"** algo, for even more sophisticated tracking of IV, skew, and kurtosis. The **"Vol Levels"** algo also tracks high/low information and can display levels from multiple baseline curves. Please contact the developer at kevin@axonetric.com for more information.

Vol Curve Publication Frequency

A trade-off exists between publishing new vol curves too rapidly (i.e. overreacting) or publishing them too sluggishly (i.e. under-reacting). Overreacting means you may be adjusting to transient noise and/or auto-fitting out real edge too quickly. Under-reacting means you could be slow to adjust to major legitimate vol moves and therefore see "imaginary" edge. Therefore the trader should find a compromise between these two regimes.

The *"curve_update_freq_secs"* setting controls the effective vol curve publication frequency. Its interpretation is straightforward: it is the number of seconds between each normal vol curve publication. The fastest allowed curve publication frequency is once per second; this limit is in place because too fast frequencies could adversely affect Metro pricing engine performance. Most users assign a value of 1 (second) or 2 (seconds) and report good results. It is not recommended to set this value too high because the algo completely ignores all IV information (and other information) coming from the markets during the "waiting period." The average time for the algo to react to a change in the market will be 50% of this setting. For example, with a setting of 1 (second), on average the algo will react to changes in IVs (publish a new curve reflecting the new IVs) within half a second.

Thus, to avoid sluggish reactions to changes in IVs, and also to prevent the algo from being deprived of market information important to various risk control features, we strongly recommend a value no more than 5 seconds for this setting. If the trader desires a more "stable" vol curve, that can be easily accomplished via the settings in the next section ("Vol Curve Evolution Over Time"), even while still using a *"curve_update_freq_secs"* of 1 or 2. Just because a new curve is published every second or two does not mean it must be much different from the prior curve.

Vol Curve Evolution Over Time

Implied volatility curves generally exhibit both continuity and mean-reversion over various time scales. However, during important events (e.g., an industry report, etc.), abrupt and sudden shocks may occur. The Dynamic Skew algo contains sophisticated logic to provide a more accurate evolution of the published vol curves over time. There are two important settings regarding this aspect.

The *"curve_stabilizer_period"* setting accepts a value of either 0 (deactivated) or 20-2000. This value controls a proprietary self-learning and adaptive statistical model which classifies changes in IV as mean-reverting IV drift versus legitimate IV shocks that should be immediately honored. While the default value of 150 will likely provide decent results in most cases, the optimal setting strongly depends on the product and/or market conditions (specifically, the "vol of vol" conditions). For highly liquid products with relatively stable IVs (e.g., rates, currencies, etc.), a higher value may be beneficial. For illiquid products, those with consistently "jumpy" IV dynamics (higher "vol of vol"), or options near expiration, a lower value will likely perform better. Lower values for this setting provide faster response to changes, while higher values provide greater stability and less short-term IV noise.

The *"curve_stabilizer_period"* setting will also accept special values 1 through 6, which allow the algo to run in a legacy mode called "static curve stickiness." This less sophisticated behavior provides a constant (non-adaptive) form of time averaging with a fixed weight. These legacy settings are provided for users who may possibly prefer this older behavior present in earlier versions of the algo. See the "Configuration Options" section for a full description of these special values.

The other important setting controlling vol curve evolution is named *"dynamicity"* and accepts a value between 1.0 and 100.0. This setting controls the algo's permissiveness of new IV curve shapes. In particular, it controls the scoring and replacement frequency of the "reconstructor's master pattern." This is a template of the vol curve shape that becomes important when bid/ask markets become abnormally wide or are missing altogether. The reconstructor logic is explained in more detail in the “Curve Reconstruction Feature” section below. Products with frequently changing curve shapes, or options near expiration, may perform better with a higher *“dynamicity”* value. Products with highly stable curve shapes may perform better with a lower *“dynamicity”* value.

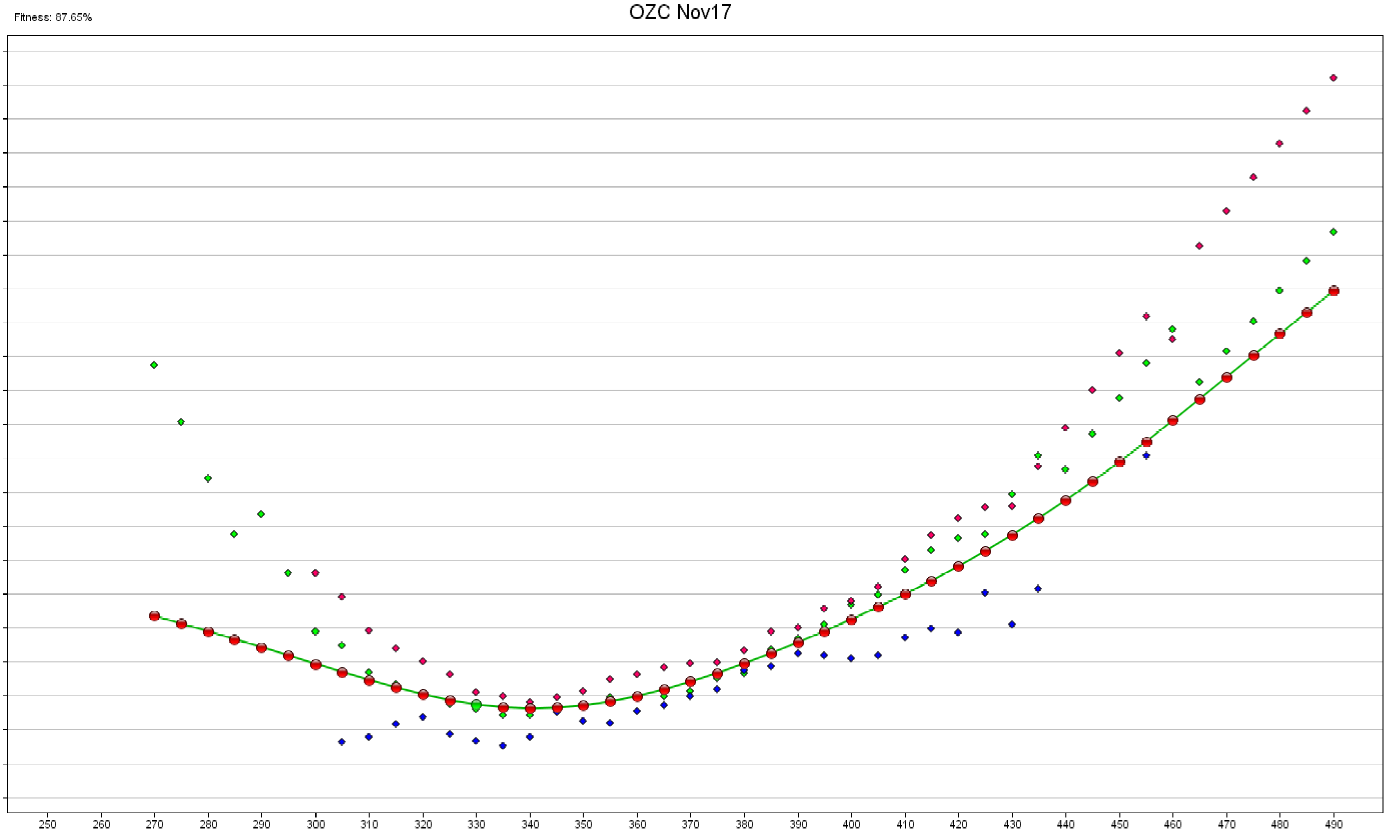
Vol Curve Smoothing

There are two independent smoothing mechanisms that together control the vol curve smoothness (i.e., degree of curve complexity). The primary mechanism is known as outlier removal logic and is controlled by the *“orl_level”* setting. This feature removes discontinuities from the vol curve, producing smoother and simpler curves that present less noise. The higher the setting, the more pronounced the smoothing effect is. The advantage of this mechanism is that, with an appropriate setting level, it usually preserves the overall curvature of the vol curve without distortion. Finding the optimal setting may require some trial and error. Too large of an *“orl_level”* setting may cause local distortions in the curve from over-smoothing. In general, the smoother a vol curve is to start with (the raw market IV curve), or the fewer outright strikes exist, the lower the value is required for this setting. This value may require maintenance on a weekly or daily basis.

An optional, independent, supplemental smoothing mechanism is controlled with the *“smoothing_amount”* setting. While this kernel-based smoothing feature works great for linear or nearly-linear vol skews, it is guaranteed to produce some distortion in U-shaped or V-shaped curves *if the value is set too high* (by pulling upwards on the bottom of the curve). This can be understood by realizing that neighboring points on both sides of any point near the curve’s bottom will tend to be higher, thus exerting an upward force on those bottom points. For volatility smiles, recommended values are 0-6, depending on the apparent level of distortion and the density of option strikes. For more linear skews, much higher values can be tolerated. This mechanism has a fairly stable effect and so usually does not require frequent adjustment.

In general, it is desirable to first find the optimal *“orl_level”* setting value (while *“smoothing_amount”* = 0). Once optimal *“orl_level”* has been established, then the user may choose to increase the supplemental *“smoothing_amount”* setting value if needed. If not needed, the *“smoothing_amount”* setting can be left at zero with no disadvantage. Volatility smiles close to expiration may take on a sharper V shape instead of the more gentle U shape. Users may find the optimal *“orl_level”* and *“smoothing_amount”* settings change as the days remaining to expiration decrease.

Special flag “2ORL” allows the trader to optionally specify a 2nd pass of the ORL logic prior to vol curve publication. In some cases, this may not appear to make much difference (or the effects are subtle), but in other cases, it may substantially improve the curve visually. This flag does slightly increase the CPU usage of the algo. Application is advised on a discretionary basis.



Dynamic Skew Fit With High Smoothness Due To “Outlier Removal Logic” And Supplemental Smoothing Applied Concurrently

Curve Reconstruction Feature

Another useful feature in the algo is the “curve reconstruction” logic, also referred to as the reconstructor. This feature allows the algo to remember a previous curve (known as a “master pattern” or template), which previously scored highly in certain metrics of quality. The criteria used to determine how eligible any instantaneous curve is to become the new master pattern (at any given time) include:

- The average tightness of current markets in the 5-55Δ range. Tighter is better.
- The degree to which the algo’s published vol curve fits the midpoint of these same markets. The closer to the midpoint, on average, the better.
- The amount of time that has elapsed since the preexisting master pattern was established. The more time that elapses, the more likely the algo will choose a new master pattern. During the evening sessions, a longer time may elapse before the algo is likely to replace the master pattern (relative to the day session) and this can also be controlled by a special flag.

The shape of the master pattern itself experiences no time decay and is remembered exactly as it was (when first encountered). The master pattern is even remembered if the algo is stopped or the server is rebooted. For example, the last good master pattern from before the market close can be used by the algo to recreate spotty markets that may exist during the first few minutes of the evening open (even though the server has since been rebooted and the algo restarted). The master pattern can be used to recreate missing bids or asks, which is especially useful if there is a sudden liquidity crisis and many markets are pulled.

The following Configuration settings affect various aspects of the reconstructor:

- Parameter *“dynamicity”* controls how frequently master patterns tend to be replaced by new ones. Higher values of this setting allow new master patterns to become established more easily. However, in some expirations, retaining an older (but higher quality) master pattern may be beneficial and the user can specify a lower value accordingly.
- Special flag “KEOD” will prevent any new master pattern from being selected during the evening session. Assigning this flag will force the algo to use the final master pattern from the day session for the entire evening, which may be beneficial in many products where evening session’s markets are less reliable that the day session’s markets.
- Special flag “INIT” allows the user to “draw” a custom IV curve in the Model Settings screen (while the algo is off), publish it, then turn on the algo and force the algo to take this user-drawn vol curve as its initial master pattern. This can be useful if the trader is unsatisfied with the Dynamic Skew algo’s attempts to model a specific expiration (particularly in deep back months with few markets). However, the Assigned curve type does contain many control points so drawing a curve manually could be a meticulous task.

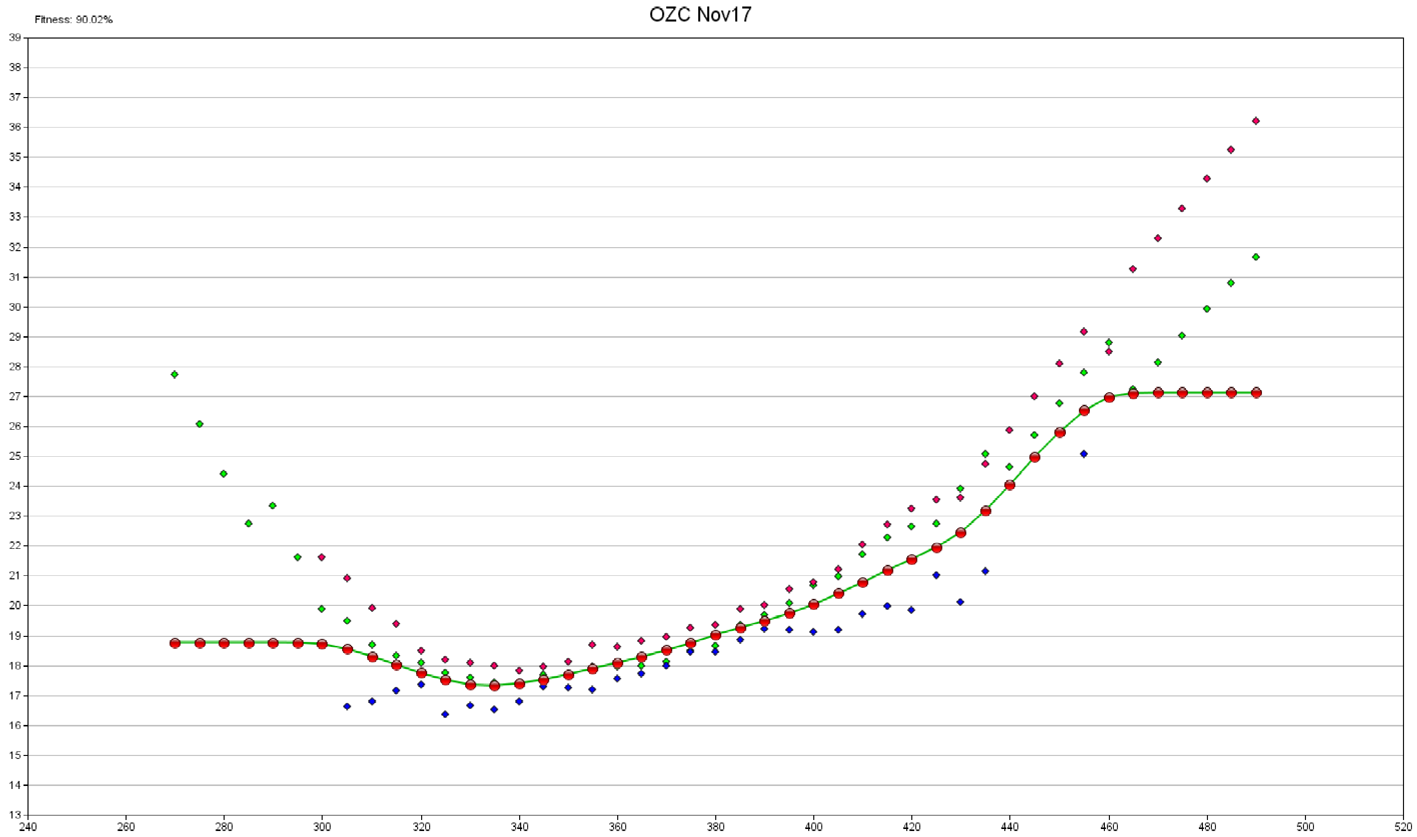
- Special flag “RESET” allows the user to force the algo to delete any previous saved master pattern from the database. This will usually cause the algo to quickly establish a new master pattern once the algo is restarted (assuming the markets are open, which is a prerequisite to establishing a new master pattern). This flag can be useful in the rare event the algo has established an invalid or corrupt master pattern.
- Debug flag “XRECON” can force the algo to omit the curve reconstruction logic altogether. This flag was added for development and testing purposes and is not recommended for general use without a specific reason. In most cases, the reconstructor is a highly beneficial feature.

Wing Treatment

The algo offers two different modes for handling the curve’s wings. The primary default mode is “auto-sloping” and this involves a robust and sophisticated algorithm to automatically compute the optimal slope of the put and call wings (independently). This mode usually works quite well. But note that adjusting the market data filtering parameters (see next section) can also affect the results produced by auto-sloping.

The other wing treatment mode is called “tabletopping” and this performs a simple horizontal extension of the most outward valid two-sided market that exists on each wing. Note that the precise strike that becomes the most outward valid two-sided market does depend somewhat on the specified market data filtering settings (see next section). To enable tabletopping mode, use the special flag “TBLTOP” in the algo’s configuration. Tabletopping is most useful close to expiration or when the number of quoted strikes with two-sided markets is very small. Tabletopping is always available as a fallback mode if the auto-sloping behavior is not satisfactory.

The setting *“iv_upper_limit”* can also be useful in auto-sloping mode. This setting defines the maximum IV value allowed anywhere on the curve and therefore provides a sort of (auto-sloping + tabletopping) hybrid mode, where the tabletopping behavior at the wings can occur at a user-defined location much higher up the Y-axis (IV) than would occur by using special flag “TBLTOP”. This can be useful, for example, if an expiration has very-far-out calls that actually come down in IV relative to the primary call slope defined by the calls at closer wing strikes (forming a shape more like a bird wing).



Dynamic Skew Fit With “Tabletopping” Mode Enabled

Market Data Filtering

These settings are very important as they help the algo determine which outright option markets (and thus their IVs) are valid and also allow the algo to detect liquidity crises (abnormal widening in options markets). These settings are product-specific and also depend on time to expiration to some degree.

The first setting is *“option_min_size”* and this controls the minimum size required on a bid or ask near ATM in order to accept that price level as valid. As strikes move away from ATM, the algo internally tapers this value down towards 1 at the wing extremities. If a given market side does not have enough size, the algo will progressively examine deeper levels of the book until enough aggregate size has been encountered to meet the criterion. For example, if the user specified 3 here and an outright ATM option had a top-of-book bid showing 1 contract only, then the algo would look at the next price level directly below the bid. Let’s say there were 2 contracts showing here. The algo would then accept this 2nd price level as the valid bid because the aggregate size (1 + 2) >= *"option_min_size"* (3 here).

If not enough size is available in the whole book on a given market side, the algo will act as if the price is simply missing on that side. This setting can make the algo more robust by filtering out non-informative small bids and asks. But avoid setting this value too high—excluding too much market information can adversely affect the modeling. In many markets, a setting of 5 to 10 (or less) is sufficient. In the front month of highly liquid options (e.g. Treasury notes or bonds), substantially higher values are reasonable—but always err to the lower side with this setting if unsure.

The second setting is *"option_max_spread_width"* and this constraint is only applied after the effects of *"option_min_size"* have already been applied on both the bid and ask sides. This criterion requires that the size-validated bid and ask price levels of two-sided markets at an outright option strike cannot be further apart than the specified value (in tick units). This value applies to the spread widths near ATM—as strikes move away from ATM, the algo internally tapers this value down to 50% of the setting at the wing extremities.

A good rule of thumb is to set this value to around twice (2.0x) the typical spread width (in option ticks units) of options near ATM. Setting this value too low is dangerous because it could filter out too many legitimate strikes and thus rely too heavily on model reconstruction instead of actual market data. Setting this value excessively high is also dangerous because then the algo cannot determine liquidity crises and could try to model abnormally wide markets that would normally be handled by specialized logic (e.g., see "dual-axis sliding mode" explained next).

If the average spread width over all OTM markets in the 5-55Δ range exceeds the user-specified *"option_max_spread_width"* setting, the algo assumes there is currently a liquidity crisis and all normal curve publications will be skipped. Instead the algo will enter "dual-axis sliding mode" and will remain in this mode until the average market tightness falls back inside the *"option_max_spread_width"* setting. In dual-axis sliding mode, the algo does not create any new curves from market IV info (which is likely unreliable), but instead "slides" the last known good curve around on the X-axis (to match the current underlying price) and (optionally) the Y-axis (to match the best estimate of the current ATM vol, if a reliable estimate is available). In other words, if all markets widen out excessively, then the algo enters dual-axis sliding mode and simply shifts the last known good vol curve up/down and left/right to match the ATM vol point as best as possible.

The third setting is *"future_min_size"* and works identically as *"option_min_size"* except on the futures spread quantities. Because the underlying price is an input to the IV function, this could have a small impact on the resultant IVs. Usually a value around 5 works fine here, but options traders in products with more liquid underlying futures could specify a greater number of futures contracts here. But always err to the lower side with this setting if unsure.

Risk Control Features

Various safety features in Dynamic Skew work together to filter out and minimize the possibility of a bad vol curve publication (although it is impossible to guarantee this will never happen). In general, the algo will skip any proposed vol curve publication that triggers any of the safety features and will try again after the next *"curve_update_freq_secs"* have elapsed (although some triggered safety features will trigger re-checks more quickly).

As already explained, the first safety feature is called liquidity crisis detection. This important feature examines the primary central region of the vol curve prior to each update and computes the average spread width on these outright options. This value is then compared with the user's *"option_max_spread_width"* setting. If the average market spread width is greater than this value, then it is defined as a liquidity crisis event and the normal vol curve update is skipped; instead the algo will temporarily enter "dual-axis sliding mode" (see previous section).

These liquidity crisis events happen continuously once the market closes (as market-makers cancel or greatly widen all their quotes on market close), thus usually preventing the algo from publishing any vol curve updates while the market is closed or on break. Liquidity crisis events can also occur during publication of a number or other news, thus triggering "dual-axis sliding mode" until markets tighten down to normal again.

The second safety feature is called vol curve shape detection. This feature is based on the premise that any two consecutive vol curves should not radically differ in shape. Mathematical calculations detect the relative shape of the curve (note that absolute vol values are not incorporated, only the relative shape across the curve) and will skip any update that appears to substantially differ in shape. The algo also remembers the last published curve prior to market close and the next market opening curve will be subject to that shape constraint. If the vol curve has legitimately changed enough that the new shape should be accepted, then the user need only stop and restart the algo to allow this constraint to reset. Alternatively, the special flag "RESET" can be specified in the algo's configuration to *always* force the algo to forget the prior closing curve's shape after any server reboot and/or algo restart (although this setting is not recommended in general, as it would also erase the reconstructor's master pattern).

The third safety feature is called snap mode. Briefly, this feature prevents the algo from lagging the market excessively if the actual overall vol curve moves vertically in a rapid and sustained (not transient) way. In these cases, snap mode guarantees the publication of a fresh unbiased curve within 3 seconds *after* detection. Note, however, that the average expected time to the initial detection of such a condition is still half of the *"curve_update_freq_secs"* setting.

The fourth safety feature is called the per-strike max vol delta constraint. Large transient vol moves in just one strike (or just a few) may represent an impending liquidity crisis. If any strike has a $|(IV_{T+0} – IV_{T-1})|$ > (% constraint), it violates this rule and the entire vol curve update will be skipped. If the violation continues to persist longer than 12 seconds in only "wing" strikes, then this constraint will temporarily be relaxed. However, if the violation continues to persist longer than 2 minutes at any strike in the near ATM region, the algo will turn itself off as a safety mechanism (and also perform job exit signaling as described below).

The fifth safety feature is called theo protection. This feature examines the % of non-wing strikes where the proposed vol curve update would produce a vol value outside the market's current bid-ask IV band. The % threshold is hard-coded and varies between 30% and 50% depending on the number of interior (i.e. non-wing) strikes. Proposed vol curve updates with excessive violations will be skipped. If theo protection violations trigger consecutively and continuously for over 5 minutes, the algo will automatically self-abort.

The sixth safety feature is configurable and is controlled by the *"on_job_exit"* setting. It is obvious that any unanticipated algo stoppage / exit could be dangerous as the vol curve for the affected options expiration will become stagnant at that point. This setting therefore controls the behavior the algo takes directly before exiting (regardless if the algo stoppage was manually requested, or occurs unexpectedly for any other reason). If this safety feature is turned on, then the algo will send out a series of signals notifying Metro and some other important missions / algos of the aborted vol curve handling. The notified components include the following:

- Metro CityCenter: any mass quoting of outrights or options strategies for the affected vol curve expiration will be deactivated automatically.
- Metro RFQ Responder Mission: automatic RFQ responses should be halted for the affected vol curve expiration.
- Axonetric LLC Profiteer Engine Algo: all active missions that involve any instruments with the effected options expiration (or optionally, the whole symbol) will be automatically deactivated. Profiteer algo version 4.06 or greater is required for compatibility.
- Axonetric LLC Auto-RFQ Algo: all active missions that involve the affected options expiration (or optionally, the whole symbol) will be automatically deactivated. Auto-RFQ algo version 2.25 or greater is required for compatibility.

“Multi-Skew Risk” Functionality

The Dynamic Skew algo offers an innovative way to have a separate (independent) risk management vol curve and execution vol curve. This capability is realized by using a Metro Artificial Options Symbol in conjunction with a portfolio syncing / trade copying feature available in the algo. Many traders like the idea of executing on realtime Black-Scholes-like greeks (fixed skew), while simultaneously being able to monitor position risk with adjusted greeks derived from a vol path (floating skew). Note that the two vol curves need not be the same curve type (e.g., one curve could be Assigned and driven by the Dynamic Skew algo, while the other could be Flexible Spline, for example, and subject to manual adjustment and publication via the Model Settings page). Please note one limitation is that quoting and RFQ responding are not allowed on the artificial options symbol (although options orders are allowed and will be correctly routed to the real symbol for execution).

To demonstrate some of the various possible configurations, consider the real options symbol “LO” and an artificial options symbol the trader has created named “LOX” (which essentially clones the LO instruments under a new user-specified symbol).

Configuration Example 1

- Execution symbol LO is run with a fixed Assigned curve type, driven by the Dynamic Skew. Quoting and order execution occur normally on LO. Position and trades are synced by the algo over to the LOX artificial symbol, which is running a floating Assigned vol curve type. The algo is also configured to sync the LOX floating curve (to mirror the fixed curve on LO), as well as recalibrate the center point of the LOX vol path (slide). Trader can view accurate risk on his position via the adjusted greeks analyzed on LOX position (which is identical to his LO position). The live risk bar displaying the adjusted greeks of the copied LOX position can be pinned to the LO tradesheets for convenience.

Configuration Example 2

- Execution symbol LO is run with a fixed Assigned curve type, driven by the Dynamic Skew. Quoting and order execution occur normally on LO. Position and trades are synced by the algo over to the LOX artificial symbol, which is running a floating Flexible Spline (or Two-Sided or any other type) vol curve. The algo is not configured to sync the LOX floating curve—instead the trader is responsible for manually adjusting and publishing changes to the LOX curve and/or vol path at whatever frequency deemed fit. Trader can view accurate risk on his position via the adjusted greeks analyzed on LOX position (which is identical to his LO position).

Configuration Example 3

- Execution symbol LO is run with a floating Flexible Spline (or Two-Sided or any other type) vol curve, manually updated and published by the trader. Concomitantly, the Dynamic Skew algo is configured to run only on the LOX floating (or fixed) Assigned curve. No trade or position syncing takes place in this scenario. The trader can now open two different tradesheets, one for LO (under his control) and one for LOX (automatically modeled and updated by the Dynamic Skew algo). Trader can execute like normal on LO while also watching the LOX sheets for confirmation of his decisions. Trader can also run order-based execution algos on LOX (such as Target Finder or Profiteer algo), but he cannot quote or RFQ respond on LOX.

After the artificial options symbol has been properly created in Metro, the algo setting *“copy_trades”* can be specified in the format FromRealSymbol -> ToArtificialSymbol. For example, the setting “LO->LOX” will (unidirectionally) sync any existing position from LO to LOX in the expiration the algo is responsible for, as well as copy all trades in realtime (while the algo is running) from LO to LOX in the expiration the algo is responsible for.

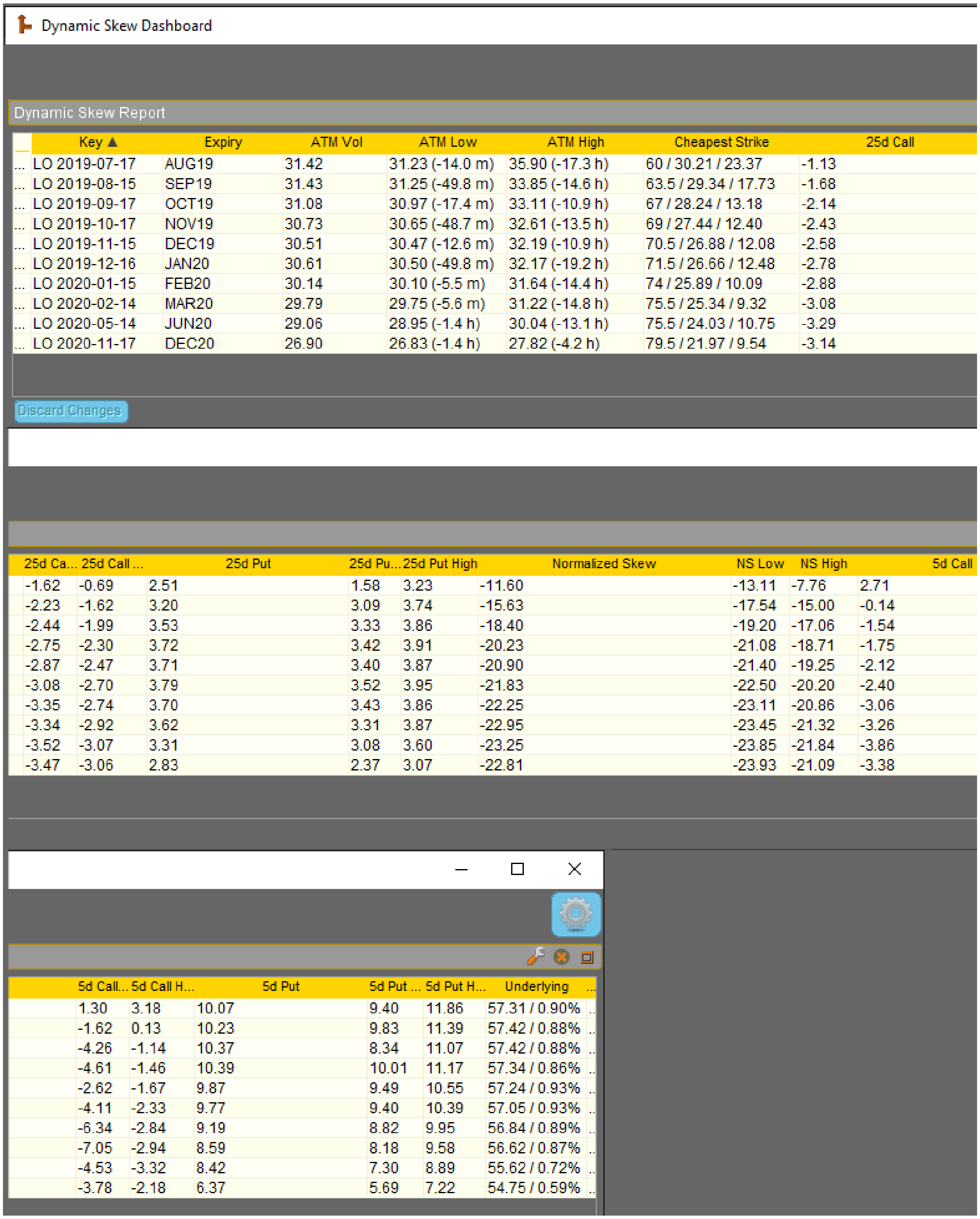
The optional special flag “SYNCCURVE” will determine whether or not the algo also updates the vol curve (and vol path for floating curve types) for the “To” artificial symbol specified in the *“copy_trades”* field (LOX in this example). If specified, the special flag “SYNCCURVE” will ensure that the LOX vol curve is updated to mirror the LO curve approximately once per minute (note that both LO and LOX must be Assigned curve types in this case, although they may possibly differ between fixed and floating). The “SYNCCURVE” updating of the artificial symbol’s vol curve will never happen more frequently than once per minute (regardless of the *“curve_update_freq_secs”* setting); this helps produce stable adjusted greeks on the artificial symbol’s copied position by not excessively updating the vol path.

Vol Report Grid

The algo also offers an informative grid report that tracks significant IV data for each expiration driven by the Dynamic Skew algo. This grid exposes vol trading opportunities with objective precision. The dashboard can be obtained via the “Load Dashboard From Server Template” menu item in Metro (after right-clicking on the winding road icon). All active Dynamic Skew job instances will report their vol statistics to the same grid, so information from the whole term structure (and possibly multiple products) is available in just one location.

This valuable market data tool displays industry standard measurements of volatility curve steepness and skew levels. It allows the trader see the “big picture” of a product’s volatility, skew dimensions, and cheapest strike. Values accompanied with timestamped high-low ranges enable the trader to identify mean-reverting trade opportunities as well as relative value plays across the term structure. Live and accurate data in the matrix format makes it easy to spot relevant items being priced “out of line”. The report grid will also display “---“ dashes in the “Last Publish” column if and when any normal vol curve update is skipped.

Reported stats for each expiration include: 50Δ Vol and its Range (tracked high and low since algo last started), Cheapest Strike and its vol, +25Δ Vol and its Range, -25Δ Vol and its Range, Normalized Skew value and its Range, +5Δ Vol and its Range, -5Δ Vol and its Range, time elapsed since the last normal vol curve publication, the current Underlying price, and a realized volatility metric on the underyling. The realized volatility metric on the underlying is a 1-hour moving window of price range (high-low) as a percentage of the current price. See the next page for an example screenshot.



Key ▲	Expiry	ATM Vol	ATM Low	ATM High	Cheapest Strike	25d Call
... LO 2019-07-17	AUG19	31.42	31.23 (-14.0 m)	35.90 (-17.3 h)	60 / 30.21 / 23.37	-1.13
... LO 2019-08-15	SEP19	31.43	31.25 (-49.8 m)	33.85 (-14.6 h)	63.5 / 29.34 / 17.73	-1.68
... LO 2019-09-17	OCT19	31.08	30.97 (-17.4 m)	33.11 (-10.9 h)	67 / 28.24 / 13.18	-2.14
... LO 2019-10-17	NOV19	30.73	30.65 (-48.7 m)	32.61 (-13.5 h)	69 / 27.44 / 12.40	-2.43
... LO 2019-11-15	DEC19	30.51	30.47 (-12.6 m)	32.19 (-10.9 h)	70.5 / 26.88 / 12.08	-2.58
... LO 2019-12-16	JAN20	30.61	30.50 (-49.8 m)	32.17 (-19.2 h)	71.5 / 26.66 / 12.48	-2.78
... LO 2020-01-15	FEB20	30.14	30.10 (-5.5 m)	31.64 (-14.4 h)	74 / 25.89 / 10.09	-2.88
... LO 2020-02-14	MAR20	29.79	29.75 (-5.6 m)	31.22 (-14.8 h)	75.5 / 25.34 / 9.32	-3.08
... LO 2020-05-14	JUN20	29.06	28.95 (-1.4 h)	30.04 (-13.1 h)	75.5 / 24.03 / 10.75	-3.29
... LO 2020-11-17	DEC20	26.90	26.83 (-1.4 h)	27.82 (-4.2 h)	79.5 / 21.97 / 9.54	-3.14

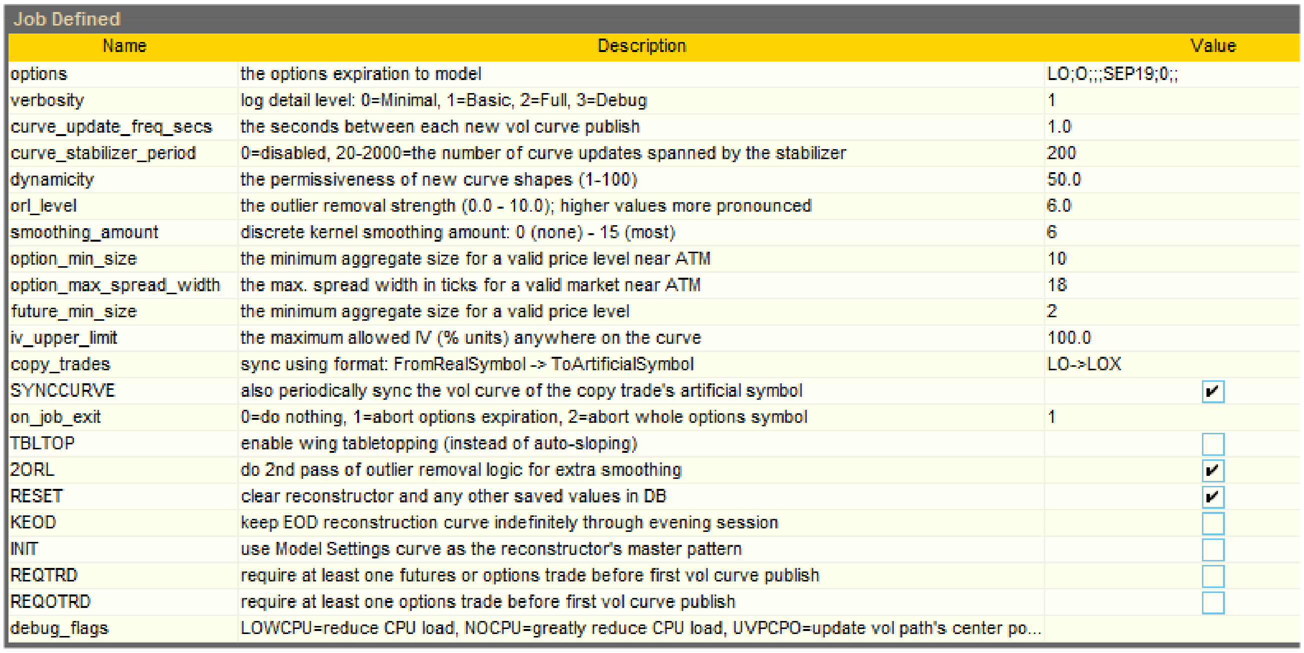
25d Ca...	25d Call ...	25d Put	25d Pu...	25d Put High	Normalized Skew	NS Low	NS High	5d Call
-1.62	-0.69	2.51	1.58	3.23	-11.60	-13.11	-7.76	2.71
-2.23	-1.62	3.20	3.09	3.74	-15.63	-17.54	-15.00	-0.14
-2.44	-1.99	3.53	3.33	3.86	-18.40	-19.20	-17.06	-1.54
-2.75	-2.30	3.72	3.42	3.91	-20.23	-21.08	-18.71	-1.75
-2.87	-2.47	3.71	3.40	3.87	-20.90	-21.40	-19.25	-2.12
-3.08	-2.70	3.79	3.52	3.95	-21.83	-22.50	-20.20	-2.40
-3.35	-2.74	3.70	3.43	3.86	-22.25	-23.11	-20.86	-3.06
-3.34	-2.92	3.62	3.31	3.87	-22.95	-23.45	-21.32	-3.26
-3.52	-3.07	3.31	3.08	3.60	-23.25	-23.85	-21.84	-3.86
-3.47	-3.06	2.83	2.37	3.07	-22.81	-23.93	-21.09	-3.38

5d Call...	5d Call H...	5d Put	5d Put ...	5d Put H...	Underlying	...
1.30	3.18	10.07	9.40	11.86	57.31 / 0.90%	..
-1.62	0.13	10.23	9.83	11.39	57.42 / 0.88%	..
-4.26	-1.14	10.37	8.34	11.07	57.42 / 0.88%	..
-4.61	-1.46	10.39	10.01	11.17	57.34 / 0.86%	..
-2.62	-1.67	9.87	9.49	10.55	57.24 / 0.93%	..
-4.11	-2.33	9.77	9.40	10.39	57.05 / 0.93%	..
-6.34	-2.84	9.19	8.82	9.95	56.84 / 0.89%	..
-7.05	-2.94	8.59	8.18	9.58	56.62 / 0.87%	..
-4.53	-3.32	8.42	7.30	8.89	55.62 / 0.72%	..
-3.78	-2.18	6.37	5.69	7.22	54.75 / 0.59%	..

Vol Report Grid (screenshot split horizontally in thirds for readability)

Configuration Options

The example screenshot below shows the job-defined Configuration options for one job instance (a single expiration). Each job instance of the algo handles one specific product and expiration. Note that because each options expiration requires its own separate algo instance (a.k.a. "job"), it is advisable to type in the product and expiration in the algo's *"Description"* field (one of the system-defined variables) so that the mapping between any algo job instance and its product+expiration can easily be discerned from other Metro screens, such as the Job Control screen.



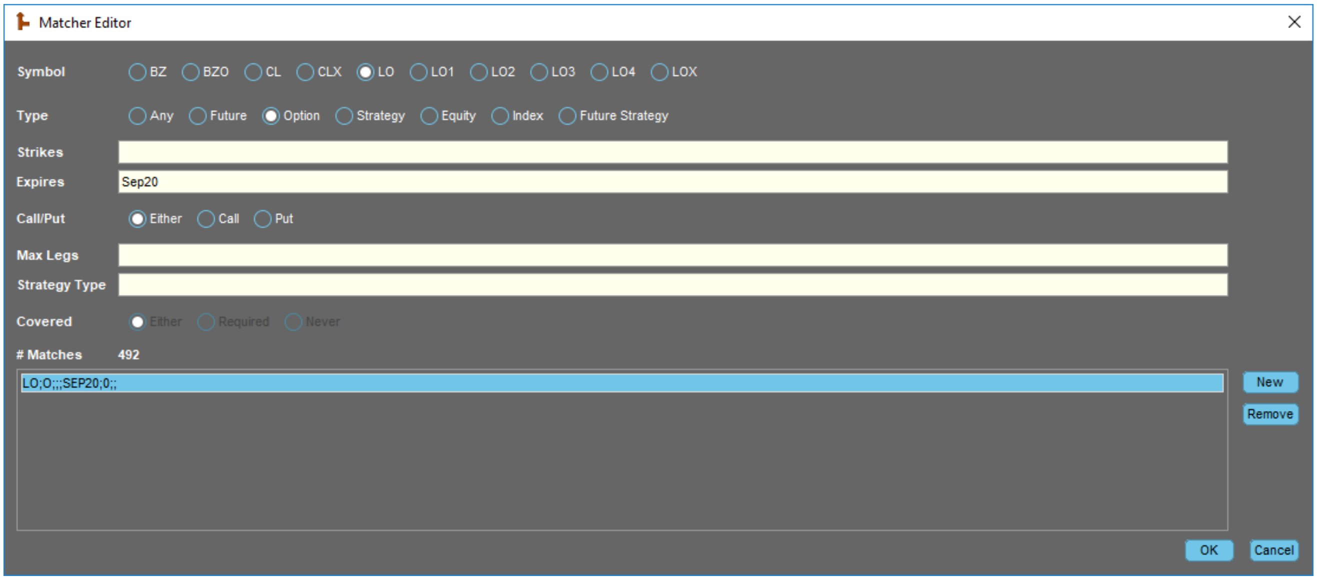
Job Defined

Name	Description	Value
options	the options expiration to model	LO;O;;;SEP19;0;;
verbosity	log detail level: 0=Minimal, 1=Basic, 2=Full, 3=Debug	1
curve_update_freq_secs	the seconds between each new vol curve publish	1.0
curve_stabilizer_period	0=disabled, 20-2000=the number of curve updates spanned by the stabilizer	200
dynamicity	the permissiveness of new curve shapes (1-100)	50.0
orl_level	the outlier removal strength (0.0 - 10.0); higher values more pronounced	6.0
smoothing_amount	discrete kernel smoothing amount: 0 (none) - 15 (most)	6
option_min_size	the minimum aggregate size for a valid price level near ATM	10
option_max_spread_width	the max. spread width in ticks for a valid market near ATM	18
future_min_size	the minimum aggregate size for a valid price level	2
iv_upper_limit	the maximum allowed IV (% units) anywhere on the curve	100.0
copy_trades	sync using format: FromRealSymbol -> ToArtificialSymbol	LO->LOX
SYNCCURVE	also periodically sync the vol curve of the copy trade's artificial symbol	☑
on_job_exit	0=do nothing, 1=abort options expiration, 2=abort whole options symbol	1
TBLTOP	enable wing tabletopping (instead of auto-sloping)	□
2ORL	do 2nd pass of outlier removal logic for extra smoothing	☑
RESET	clear reconstructor and any other saved values in DB	☑
KEOD	keep EOD reconstruction curve indefinitely through evening session	□
INIT	use Model Settings curve as the reconstructor's master pattern	□
REQTRD	require at least one futures or options trade before first vol curve publish	□
REQOTRD	require at least one options trade before first vol curve publish	□
debug_flags	LOWCPU=reduce CPU load, NOCPU=greatly reduce CPU load, UVPCPO=update vol path's center po...	

Screenshot Of A Typical Configuration For A Dynamic Skew Job Instance (One Expiration)

"options"

Double-click the value cell to pop open the Matcher Editor dialog. Click the "New" button to unlock the filter fields. Select the radio button for the options symbol, set "Type" to "Option", and then type in the expiration code for the expiration to assign to this Dynamic Skew algo instance. Each options expiration will require its own separate algo instance (a.k.a. "job"). Leave all other fields untouched. Success can be confirmed by viewing a positive number of matches at the bottom field (see image below).


Matcher Editor

Symbol ○ BZ ○ BZO ○ CL ○ CLX ● LO ○ LO1 ○ LO2 ○ LO3 ○ LO4 ○ LOX

Type ○ Any ○ Future ● Option ○ Strategy ○ Equity ○ Index ○ Future Strategy

Strikes

Expires Sep20

Call/Put ● Either ○ Call ○ Put

Max Legs

Strategy Type

Covered ● Either ○ Required ○ Never

Matches 492

LO;O;;;SEP20;0;;

“verbosity”

An integer value that controls the level of detail reported in the log.

- 0: Minimal
- 1: Basic
- 2: Full
- 3: Debug (only useful for debugging)

Recommended initial value is 1 (Basic).

“curve_update_freq_secs”

The decimal number of seconds between each normal vol curve update. The lowest allowed value is 1.0. Values greater than 5.0 are not recommended. See the “Vol Curve Publication Frequency” section for more detail.

“curve_stabilizer_period”

This integer value controls a proprietary self-learning and adaptive statistical model which classifies changes in IV as mean-reverting IV drift versus legitimate IV shocks that should be immediately honored. Valid values are either 0 (deactivated) or 20-2000. Lower values for this setting provide faster response to changes, while higher values provide greater stability and less short-term IV noise. This setting will also accept special values 1 through 6, which allow the algo to run in a legacy mode called “static curve stickiness.” This less sophisticated behavior provides a constant (non-adaptive) form of time averaging with a fixed weight:

- Setting = 0. Fixed time averaging weight of 50%.
- Setting = 1. Fixed time averaging weight of 60%.
- Setting = 2. Fixed time averaging weight of 70%.
- Setting = 3. Fixed time averaging weight of 80%.
- Setting = 4. Fixed time averaging weight of 90%.
- Setting = 5. Fixed time averaging weight of 95%.

- Setting = 6. Fixed time averaging weight of 0% (truly and totally deactivated).

"dynamicity"
This decimal value controls the algo's permissiveness of new IV curve shapes. Allowed values are between 1.0 and 100.0. Higher values are more permissive of changes in vol curve shape and lower values are more resistant to deviations in vol curve shape. The optimal value depends on the dynamics of the product and expiration. See the "Vol Curve Evolution Over Time" section for more detail.

"orl_level"
This decimal value controls the strength of the proprietary outlier removal logic (ORL). Allowed values are 0.0 (deactivated) to 10.0 (strongest effect). Too low of a level may result in a jagged or noisy curve, while too high of a level may produce curve distortion due to over-smoothing. The optimal value varies by market and by expiration and may require some trial and error to determine. The optimal value may also change over time, requiring some occasional adjustments to maintain the best curve. The most common range is roughly between 2.0 and 6.0, although various products and expirations may require values outside this range. Expirations with few strikes, or those with a smooth market IV curve, generally have a smaller optimal value for this setting. See the "Vol Curve Smoothing" section for more detail.

"smoothing_amount"
This integer value controls the strength of the supplemental kernel-based smoothing feature. Allowed values are 0 (deactivated) to 15 (strongest). Too high of a value will distort curvature by pulling upward on the bottom of U-shaped or V-shaped curves; recommended values for these curve shapes are 0-6, depending on how much supplemental smoothing may be required and the apparent level of curve distortion. With high outright option strike price density (i.e. many strikes listed by the exchange), higher values can usually be tolerated. For more linear skews, much higher values can be tolerated. This setting is fairly stable over time. See the "Vol Curve Smoothing" section for more detail.

"option_min_size"
This integer value controls the aggregate size required on a bid or ask price level near ATM in order to accept that price level as valid. As strikes move away from ATM, the algo internally tapers this value down towards 1 at the wing extremities. If not enough size is available in the whole book on a given market side, the algo will act as if the price is simply missing on that side. Recommended value depends on the typical depth of the top-of-book market. Avoid setting this value too high otherwise too much information could be filtered out. See the "Market Data Filtering" section for more detail.

"option_max_spread_width"
This integer value controls the maximum allowed distance (spread width) in ticks between the size-validated bid and ask price levels near ATM. As strikes move away

from ATM, the algo internally tapers this value down to 50% of the setting at the wing extremities. This criterion only applies to two-sided markets where both sides have ample size (with respect to *"option_min_size"*). Spreads that are too wide will be disregarded and the algo will use mathematical interpolation to reconstruct vol at these strikes. Avoid setting this value too low otherwise too much information will be filtered out. Also avoid setting this value excessively high otherwise the algo may not correctly detect liquidity crises. Recommended initial value is about twice (2.0x) the typical spread width (in ticks) of a normal, tight market at the ATM strike. See the "Market Data Filtering" section for more detail.

"future_min_size"

This integer value controls the aggregate size required on a bid or ask price level of the underlying futures contract in order to accept that futures price level as valid. Recommended value depends on the typical depth of the top-of-book market in the underlying futures contract. See the "Market Data Filtering" section for more detail.

"iv_upper_limit"

This decimal value defines the maximum IV value allowed anywhere on the curve and therefore allows a sort of (auto-sloping + tabletopping) hybrid mode, where the tabletopping behavior at the wings can occur at a user-defined location much higher up the Y-axis (IV) than would occur by using special flag "TBLTOP". If you wish to bypass this behavior, simply assign a very large value here (the default value of 200.0 is usually sufficient since few products ever reach 200% volatility). See the "Wing Treatment" section for more detail.

"copy_trades"

This text value allows for "multi-skew risk" configurations, in conjunction with an artificial options symbol defined in Metro. Leave blank to omit these configurations, otherwise specify the real and artificial options symbol in the following format: FromRealSymbol -> ToArtificialSymbol. For example, the setting "LO->LOX" will (unidirectionally) sync any existing position from LO to LOX in the expiration the algo is responsible for, as well as copy all trades in realtime (while the algo is running) from LO to LOX in the expiration the algo is responsible for. See the "Multi-Skew Risk Functionality" section for more detail.

"SYNCCURVE"

This special flag can be (optionally) assigned only when the *"copy_trades"* field is also defined (non-empty value). This is used in configurations where the artificial options symbol's vol curves are either Fixed Assigned or Floating Assigned, and the Dynamic Skew algo is also responsible for maintaining these secondary curves. If specified, the special flag "SYNCCURVE" will ensure that the artificial options symbol's vol curve (and also vol path for floating curves) is updated to mirror the real symbol's vol curve approximately once per minute (regardless of the *"curve_update_freq_secs"* setting). See the "Multi-Skew Risk Functionality" section for more detail.

"on_job_exit"

This integer value controls the behavior on algo exit, in both intended and unintended cases. The allowed values are:

- 0: Do nothing (i.e., not protected against a possible stagnant vol curve)
- 1: Abort Metro and algo activity in the affected options expiration via various signals. Other options expirations in the same symbol will remain unaffected.
- 2: Abort Metro and algo activity in the affected symbol (all options expirations for the symbol) via various signals

Recommended value is 1. See the "Risk Control Features" section for more detail.

"TBLTOP"

This special flag enables the tabletopping wing treatment mode. If not specified, the algo will always use the standard auto-sloping wing treatment mode. Auto-sloping may not always behave properly (or may not be desirable) for options close to expiration, deep back months, or expirations that have very few strikes quoted. See the "Wing Treatment" section for more detail.

"2ORL"

This special flag enables a 2nd pass of the outlier removal logic (ORL) as a post-processing step. It generally creates an even smoother curve, although the effects may be subtle. Sometimes, however, it does lead to substantial improvement in curvature. This flag may increase the CPU usage of the algo. Application is advised on a visual discretionary basis. See the "Vol Curve Smoothing" section for more detail.

"RESET"

This special flag tells the algo to reset any persisted state upon the next algo restart. This includes refreshing the grid report reference, erasing any current/saved reconstructor master pattern, as well as deleting any previously saved vol curve shape features from the database (note that a currently violating vol curve shape constraint can also be reset simply by restarting the algo). This flag is advised to only be used as required. One scenario might be if an old or invalid reconstructor master pattern is causing visible distortions in the curve and needs to be cleared out.

"KEOD"

This special flag (Keep End-Of-Day) will prevent any new master pattern from being selected by the reconstructor during the evening session. Assigning this flag will force the algo to only use the existing saved master pattern from the database (usually the final master pattern from the day session) for the entire evening, which may be beneficial in many products where evening session markets are less reliable.

"INIT"

This special flag allows the trader to force the algo to use a manually designed curve (from the Model Settings page) as the reconstructor's master pattern upon algo restart.

The Model Settings page curve must be of the Assigned type. Note that the curve is not extracted from the Model Settings page until the first normal curve publication would normally occur, so there may be some latency between the algo being started and the curve being extracted (if, for example, the markets are currently closed). This feature is intended as a "last resort"; if all else fails, the trader can give the algo manual guidance via the Model Settings page. This may be useful for expirations with very few markets or deep back months.

"REQTRD"

This special flag requires the algo to observe at least one market trade in the options (or linked underlying future) before it publishes the very first vol curve. The advantage of this flag is that it prevents any possible bad vol curve fits after server reboot (during market close time, prior to evening market open) due to bogus market data feed info (a known CME issue). The downside is that if the algo is stopped and re-started midday, the very first fit will be delayed until the first trade is seen (which could be a bit in some back months).

"REQOTRD"

This special flag is nearly identical to the *"REQTRD"* flag. The only difference is that this flag explicitly requires an options trade to be observed before it publishes the very first vol curve (observed underlying trades do not count). This flag can be useful if the underlying market is open when the options market is still closed. Options market IV info is generally not dependable while the options market is closed.

"debug_flags"

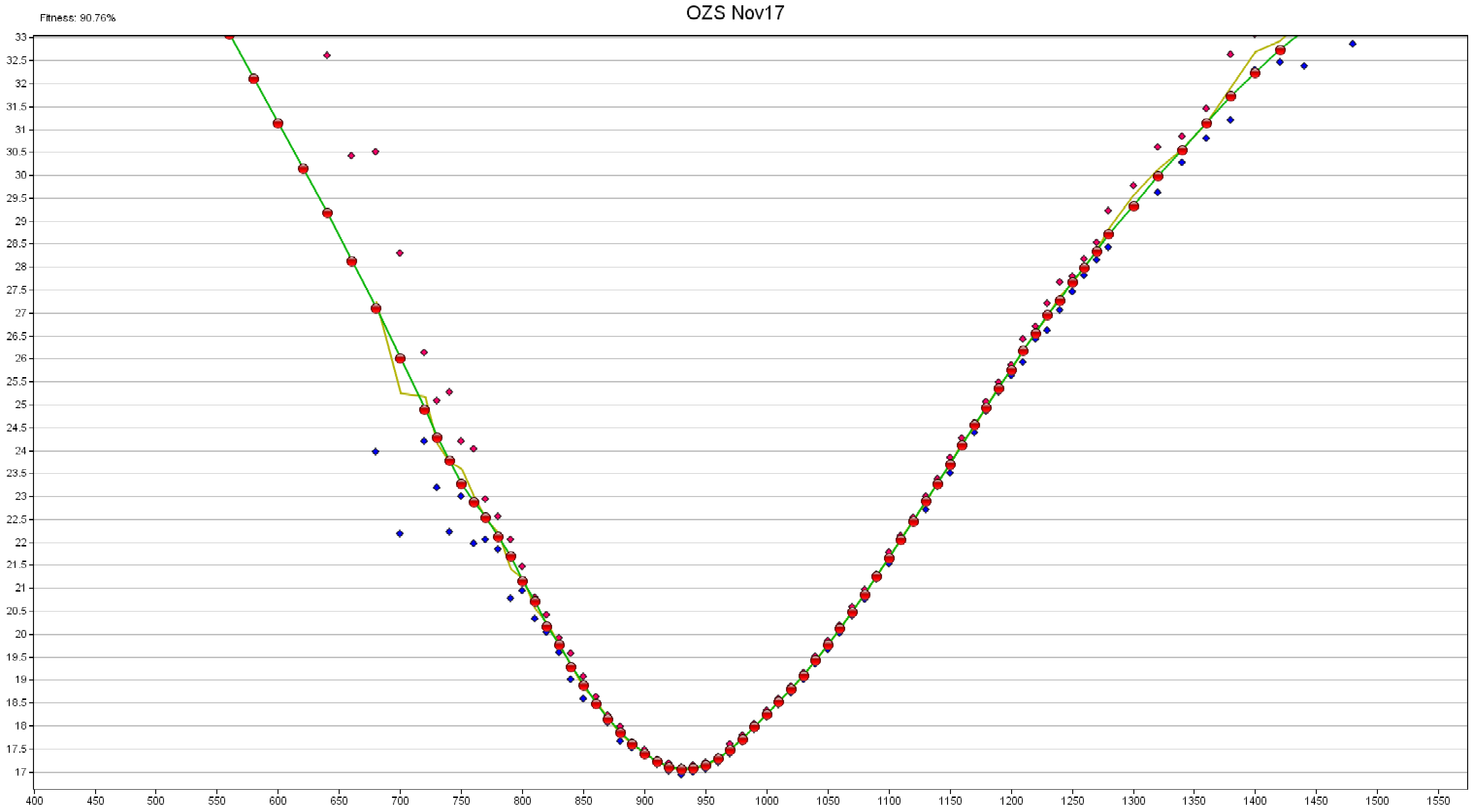
This text field allows the user to assign various optional rare flags controlling algo behavior. Most of these flags are intended for development and troubleshooting purposes, although users may find some of them useful on occasion. Multiple flags can be assigned by separating them with commas: for example, "XRECON,LOWCPU" (no double-quotes required). All flags should be entered in uppercase. Valid flags include:

- **LOWCPU**: this debug flag allows the user to force the algo to consume less CPU resources. The ORL logic is one of the most computationally intensive sections, and this flag reduces the CPU load there by sacrificing some smoothing quality in subtle ways. In most cases, the difference is barely visible, if at all. If CPU burden is an issue, users should also consider unchecking *"2ORL"* flag (if assigned), as well as increasing the *"curve_update_freq_secs"* setting so the algo's processing routines are called less frequently.
- **NOCPU**: this debug flag is essentially the same as *"LOWCPU"*, but with a greater effect. It reduces ORL logic computations even further, usually without significant visible degradation of curve smoothness. While not true in the literal sense of "no CPU usage", this flag does have at least twice the CPU reduction effect as *"LOWCPU"*.
- **UVPCPO**: this debug flag stands for "Update Vol Path's Center Point Only", and can optionally be assigned when the algo is responsible for a floating vol curve.

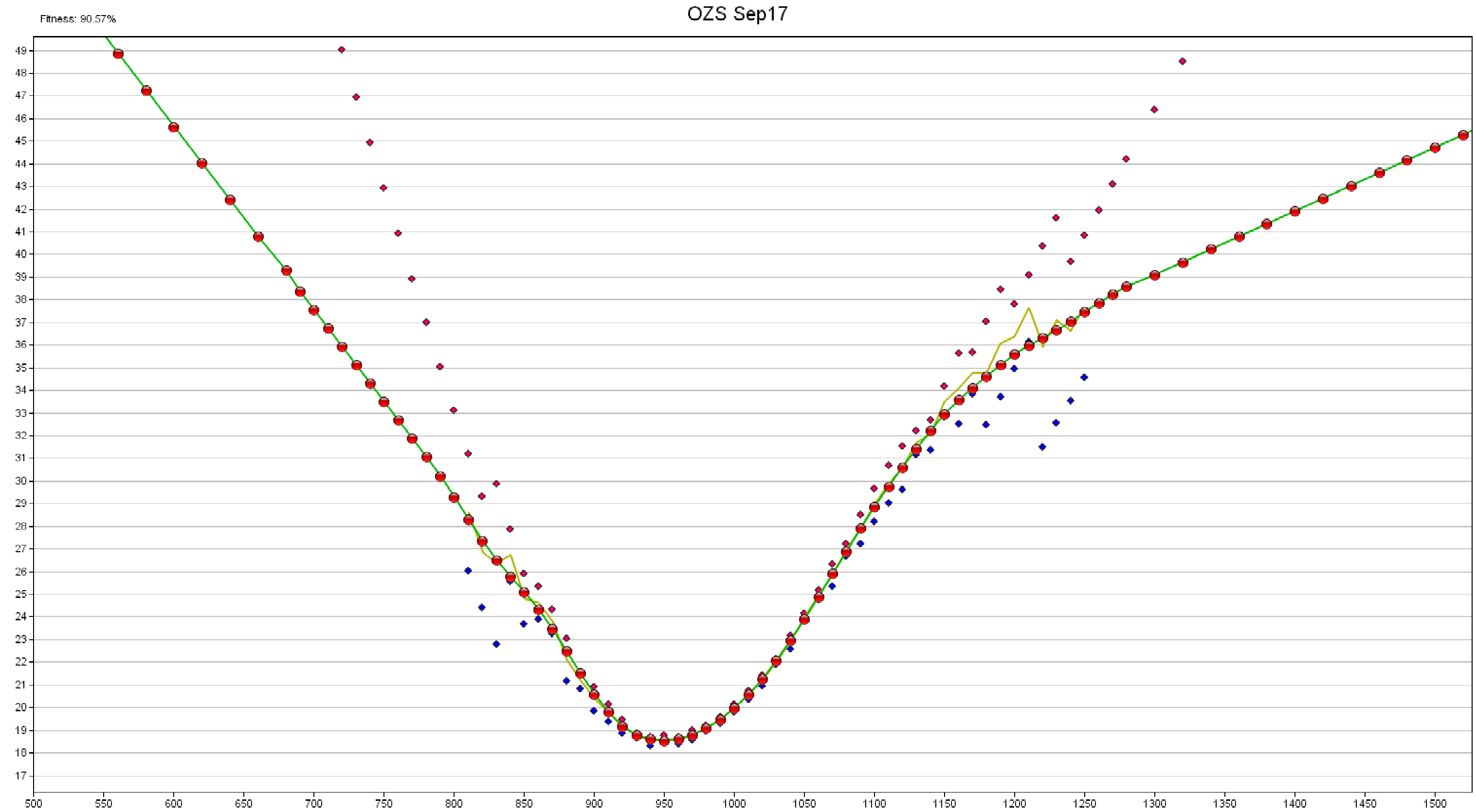
In this mode, only the center (middle) point of the vol path will be updated to match the ATM price and vol. Normally all three points of the vol slide are shifted (translated) to account for the X- and Y-axis changes in the center point. The advantage to *“UVPCPO”* is that the adjusted greeks for the portfolio are more stable (from update to update) than under the normal mode; the disadvantage is that the relative shape of the vol slide can and will change with large moves in ATM vol. If the trader is not watching, the concavity could even potentially reverse.

- **CTMAN**: this debug flag will force the algo to also copy trades for manual trades (normally manual trades are not copied). This flag is only relevant if the *“copy_trades”* setting is specified.
- **XRECON**: this debug flag allows the user to force the algo to skip the curve reconstruction feature altogether and indefinitely. Note that this differs from the *“RESET”* flag; the *“RESET”* flag just clears any saved master pattern from the database—in most cases, the reconstructor will quickly assign a new master pattern and reconstruction processing will commence anew.
- **XVCSF**: this debug flag allows the user to force the algo to skip the vol curve shape feature safety check. Because this feature is adaptive, the vol curve shape check is rarely a problem and often performs quite well to prevent transient or abrupt market data from adversely affecting the published curves. However, if the user has reason to believe this safety feature is a problem after inspecting the Log Viewer, he may deactivate it here.

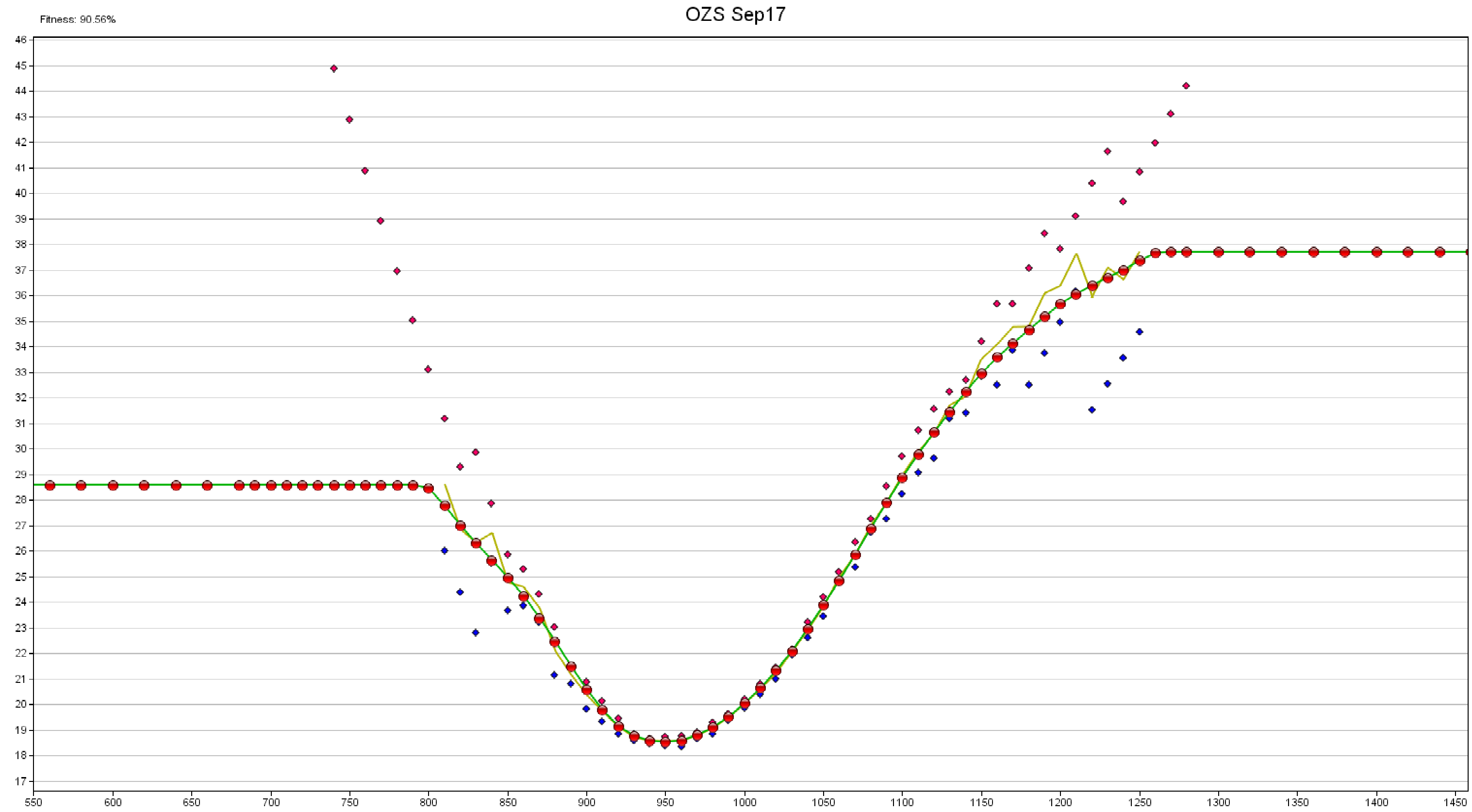
Appendix



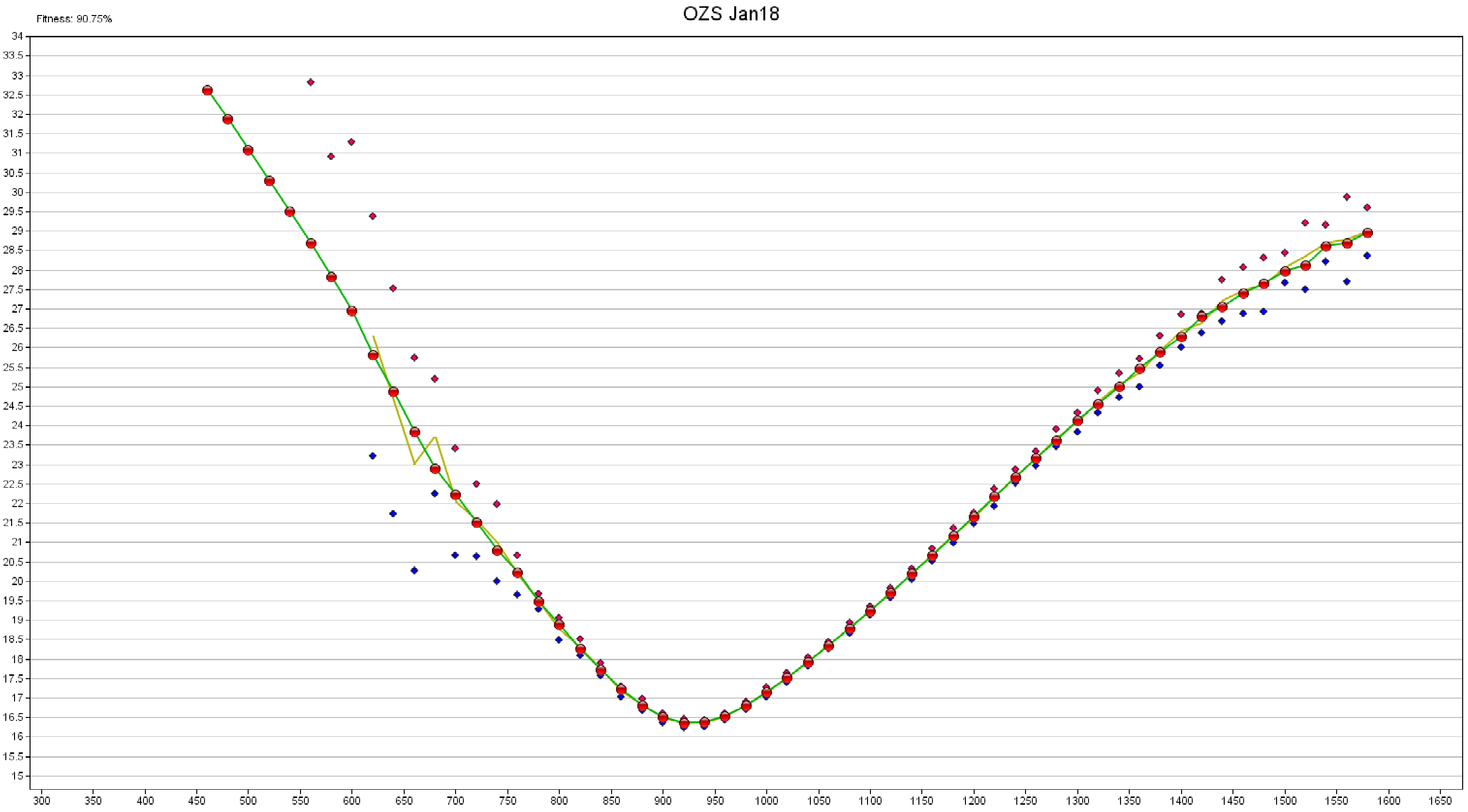
Nov. 2017 Soybeans Options – Day Session – Dynamic Skew Fit
(thin yellow line shows implied vol midpoints)



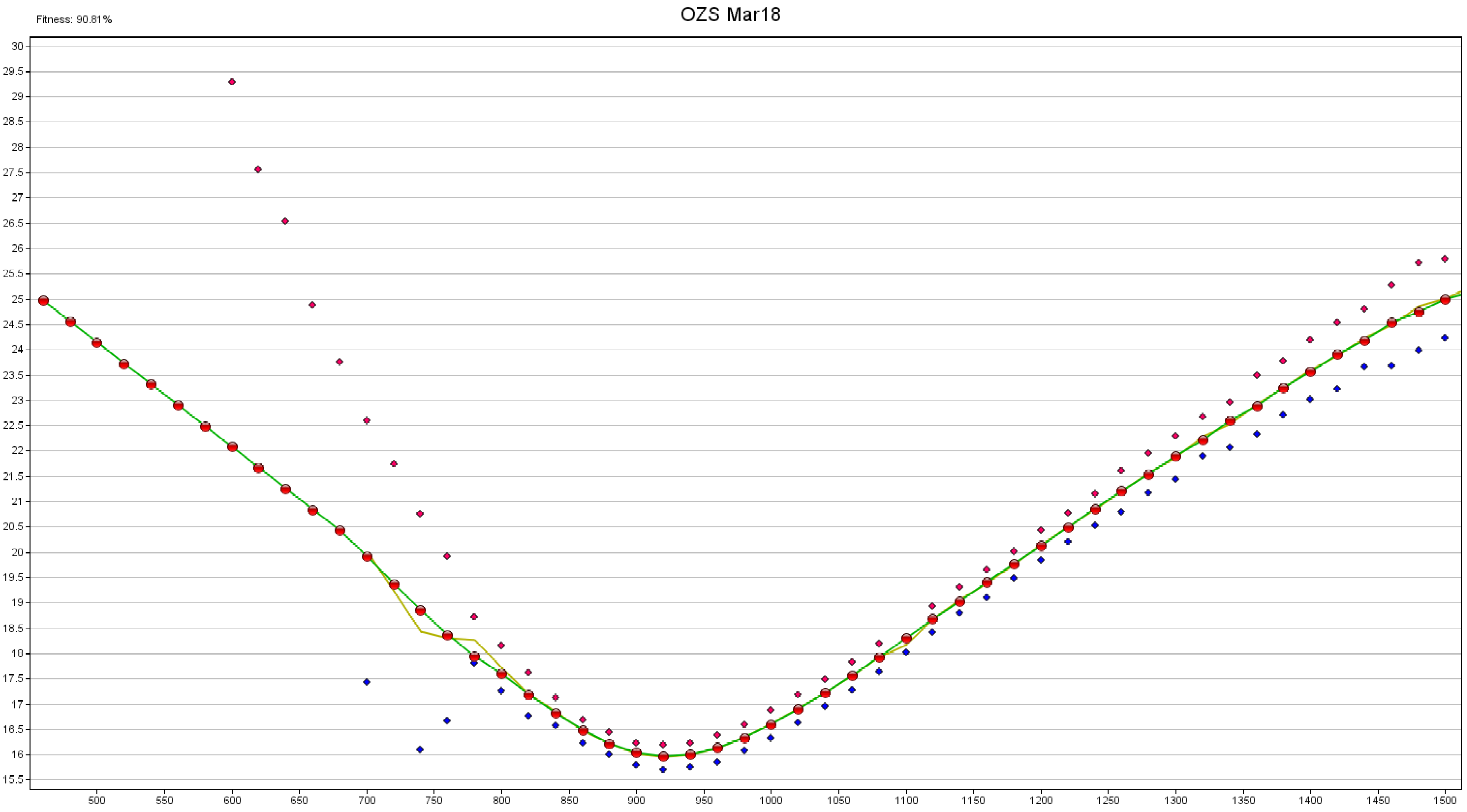
Sep. 2017 Soybeans Options – Day Session – Dynamic Skew Fit



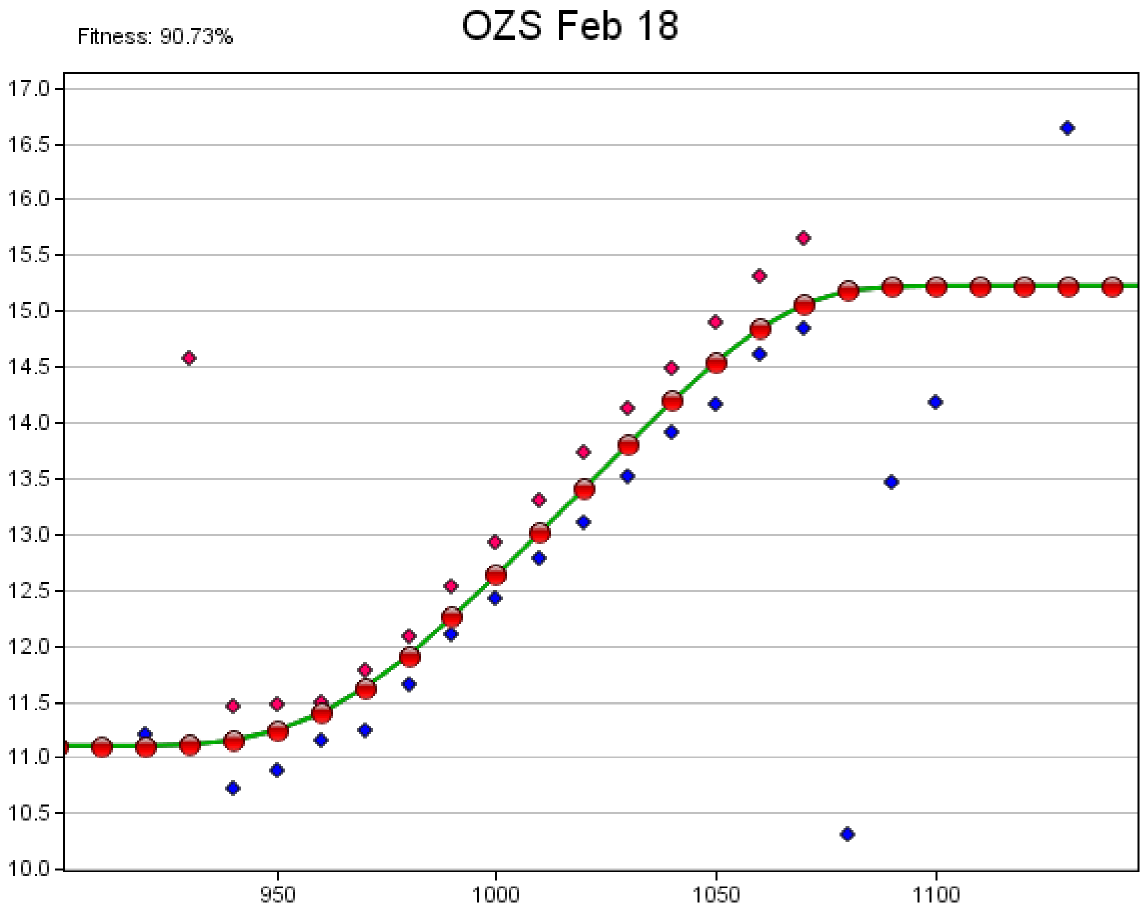
Sep. 2017 Soybeans Options – Day Session – Dynamic Skew Fit w/ Tabletopping



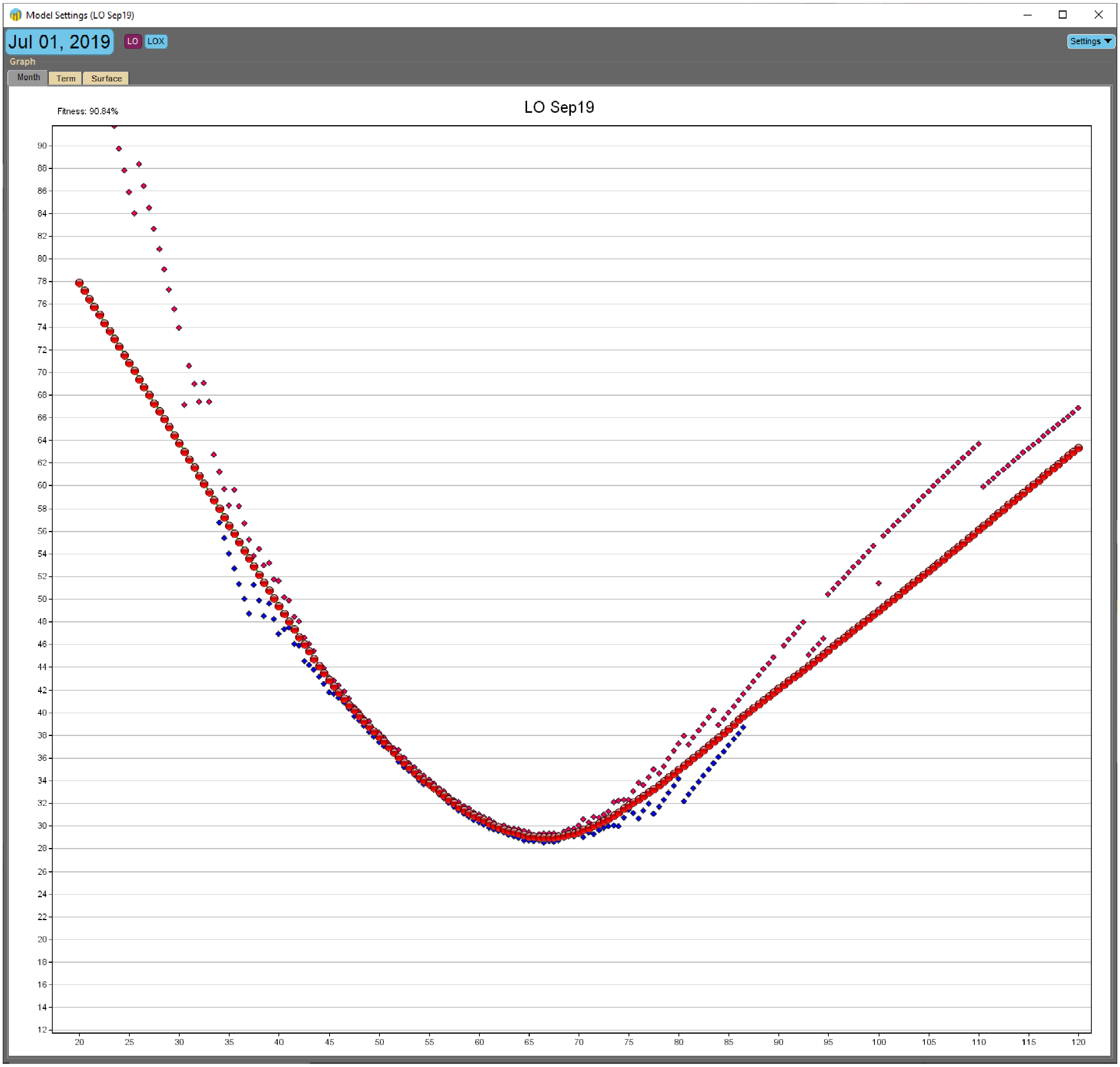
Jan. 2018 Soybeans Options – Day Session – Dynamic Skew Fit



Mar. 2018 Soybeans Options – Day Session – Dynamic Skew Fit



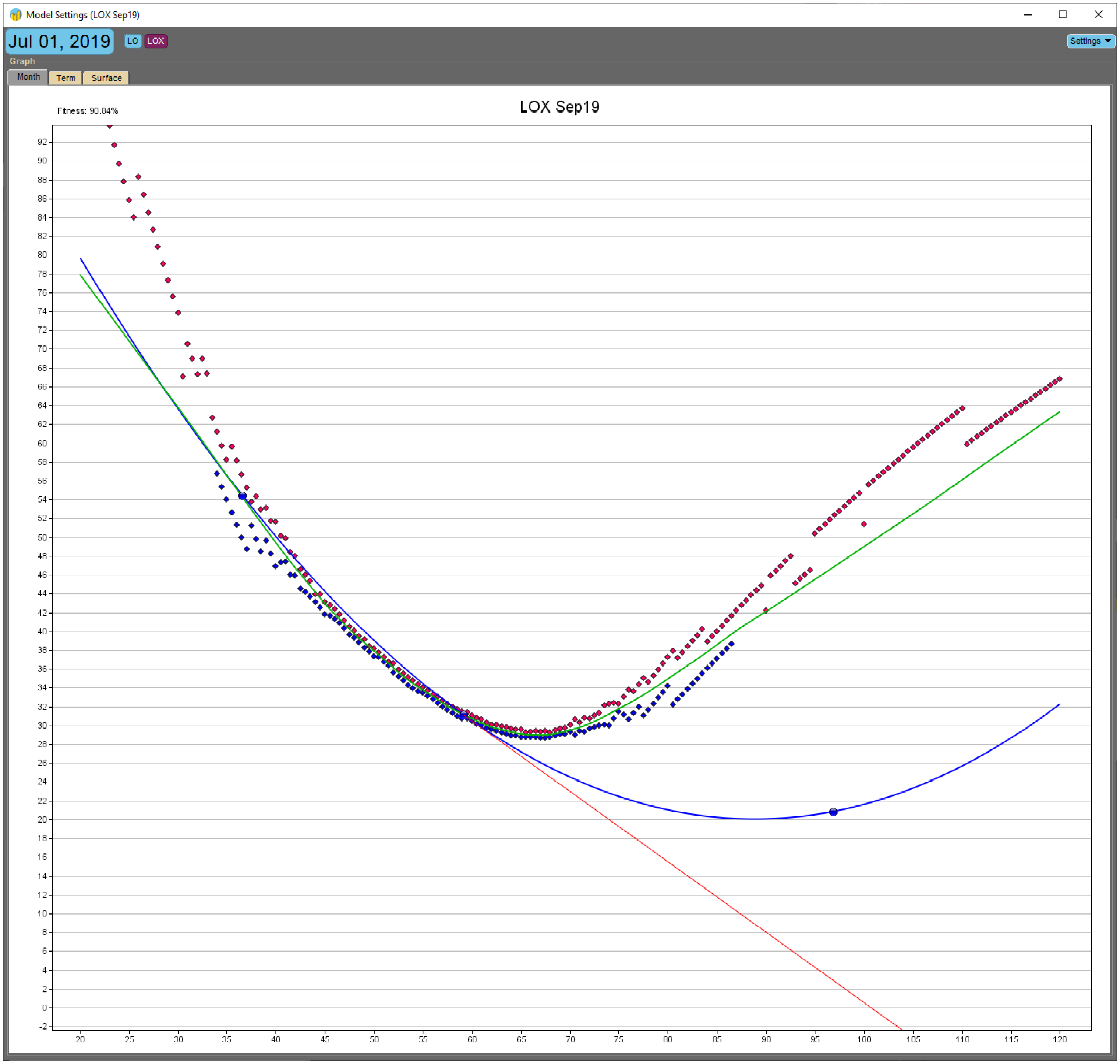
Feb. 2018 Soybeans Options – Overnight Session – Dynamic Skew Fit
(the algo is able to model sparse strikes with noisy IV data)



Jul 01, 2019

Fitness: 90.84%

Sep. 2019 Crude Oil Options – Fixed Skew – Dynamic Skew Fit



Model Settings (LOX Sep19)

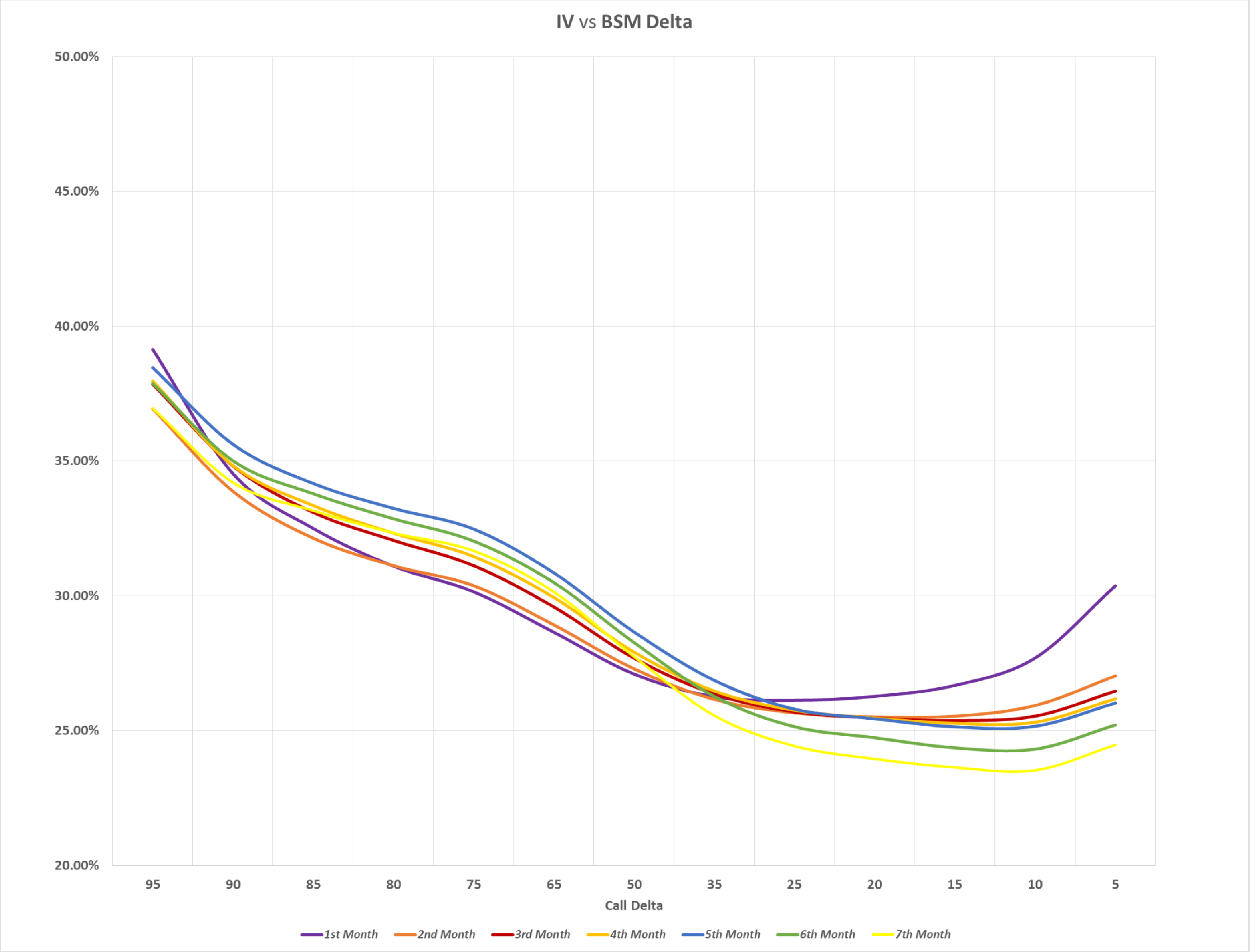
Jul 01, 2019

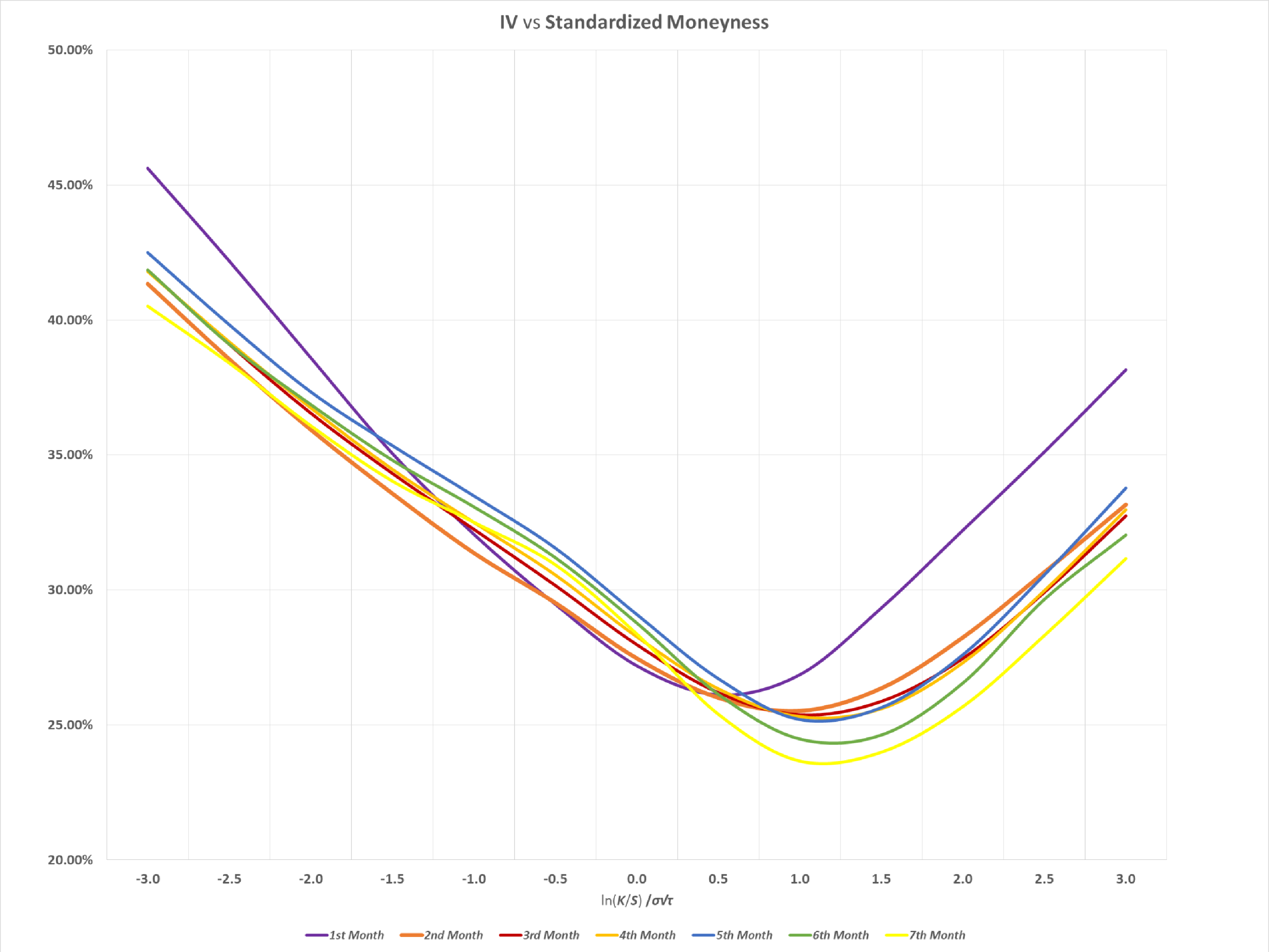
LOX Sep19

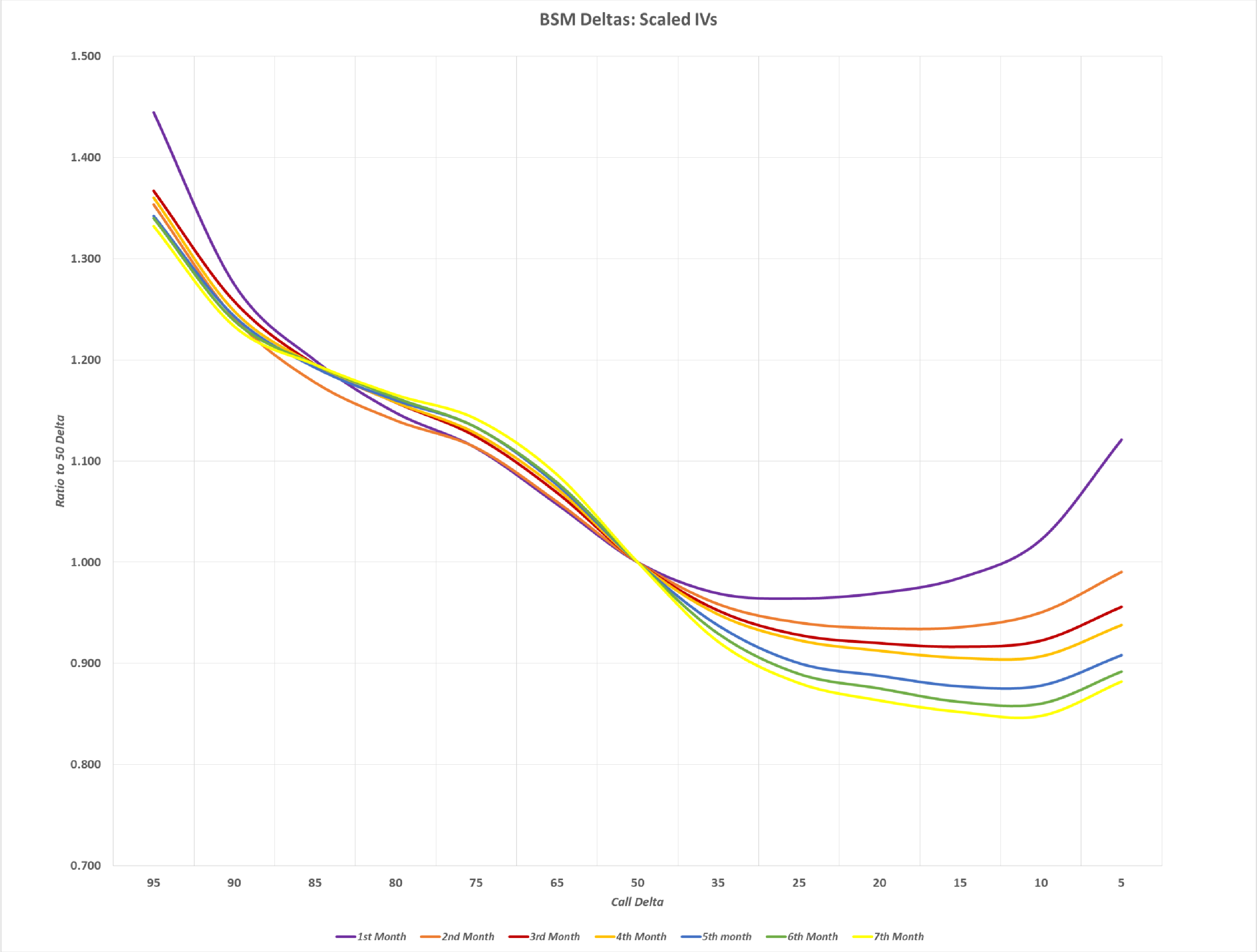
Fitness: 90.84%

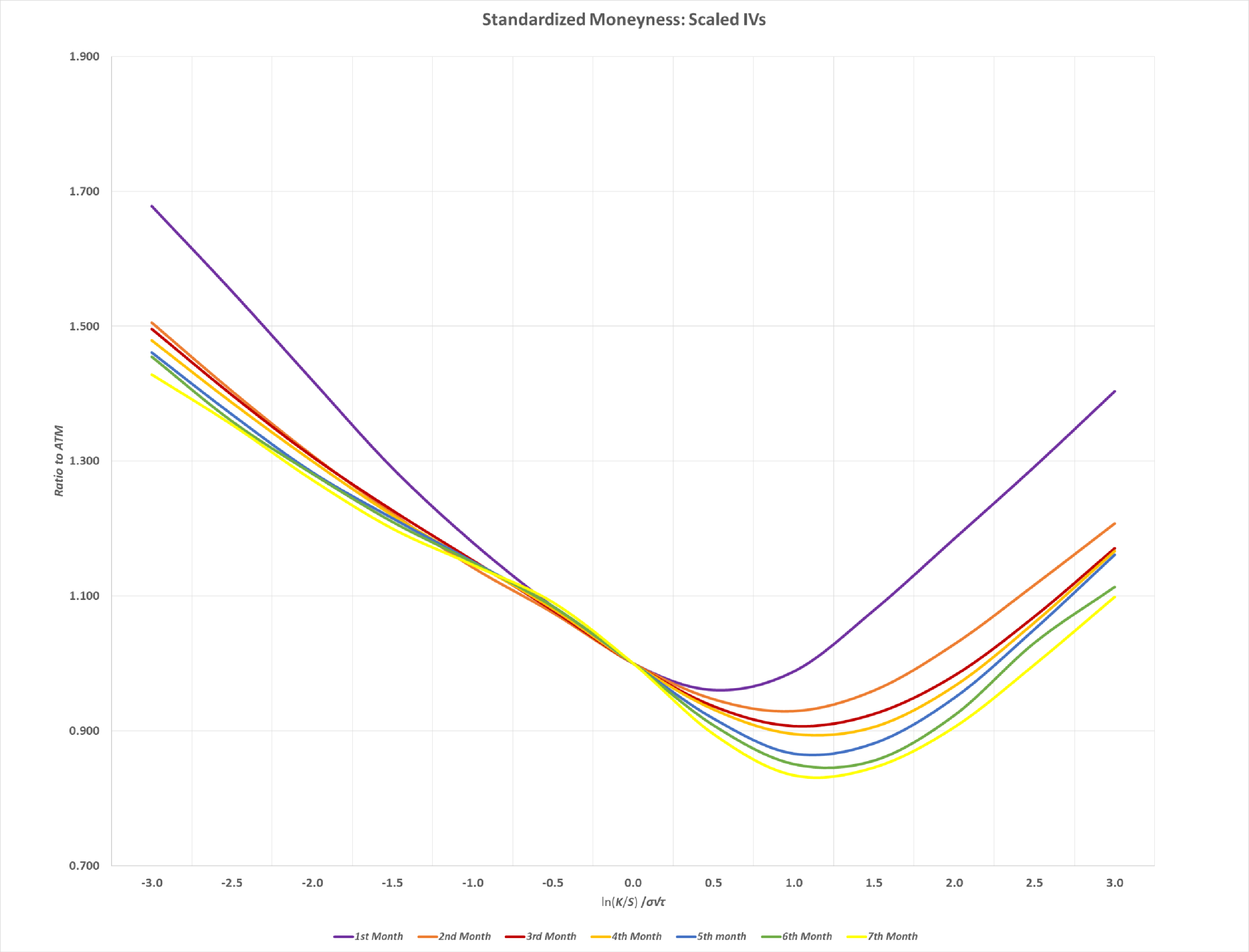
Sep. 2019 Crude Oil Options – Floating Skew – Dynamic Skew Fit

The four Excel charts below were created from vol curves generated by the Dynamic Skew algo across the CME crude oil options (LO) term structure. The term structure correlations are apparent from multiple perspectives. These important ratios and metrics can be tracked and monitored in the new **“Vol Levels”** algo, making it an ideal analytical tool to pair with the Dynamic Skew algo. The combined use of these two complementary algos allows traders to quickly identify and pinpoint intra-day and "big picture" trading opportunities.




IV vs Standardized Moneyness
50.00%
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
ln(K/S) /σ√τ
1st Month
2nd Month
3rd Month
4th Month
5th Month
6th Month
7th Month


BSM Deltas: Scaled IVs
1.500
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
Ratio to 50 Delta
95
90
85
80
75
65
50
35
25
20
15
10
5
Call Delta
1st Month
2nd Month
3rd Month
4th Month
5th month
6th Month
7th Month


Standardized Moneyness: Scaled IVs
1.900
1.700
1.500
1.300
1.100
0.900
0.700
Ratio to ATM
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
ln(K/S) /σ√τ
1st Month
2nd Month
3rd Month
4th Month
5th month
6th Month
7th Month