SANOS

Smooth Arbitrage-free Non-parametric Option Surfaces

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Motivation

Theory...

- Most of classic quant finance assumes the existence of an arbitrage-free continuous market of European options
- Ideally it's smooth so we can compute Dupire's local volatility.

... and practise:

Real option markets are

- ... discrete
- ... referenced in cash strikes and dates
- ... have bid/ask spreads which may nor may not allow for arbitrage(*)
- ... with listed expiries from 0DTE to years out.

(*) A static snapshot of aggregated data may exhibit arbitrage without representing true trading opportunities.

Motivation

Task

- Find an universal smooth arbitrage-free interpolation in strike and expiries of real market data
- Discuss existence if there exists no *actionable arbitrage* e.g. considering prevailing bids and asks a trade I can execute today which never loses money and sometimes makes money.

Properties

- **Fast:** we want to use it inside machine learning training loops ("Deep Hedging") and in high(-ish) frequency trading settings.
- **Robust:** minimize fiddling with numerical parameters.
- **Universal (non parametric):** works for more or less everything.

SANOS does all that and more.

Motivation

Program:

- Historic context / Motivation
- Arbitrage
- Linear fitting
- SANOS
- Examples

Motivation

Historic Perspective

- Interpolate implied volatility / variance / sqrt of variance with parametric forms or splines
  - First reference I found is [1]
  - No really useful conditions such that a spline can be made arbitrage-free per expiry and across expiries
  - Plenty of papers with heuristics e.g. the procedure of [2]

- Fit a stochastic vol / levy / other model. Then add local vol on top [3].
  - Works – in face the "particle method" is remarkable robust vs small issues in arbitrage.
  - Too heavy for large scale or performance sensitive approaches
    - Initial fit requires minimizing over an FFT;
    - LV overlay requires *at least* a 2D forward PDE sweep on a dense grid.

[1] On Estimating the Risk-Neutral Probability Distribution Implied by Option Prices, Mayhew, 1995
[2] Arbitrage-free smoothing of the implied volatility surface, Fengler, 2005
[3] The Smile Calibration Problem Solved, Guyon et al, 2014

Motivation

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Historic Perspective

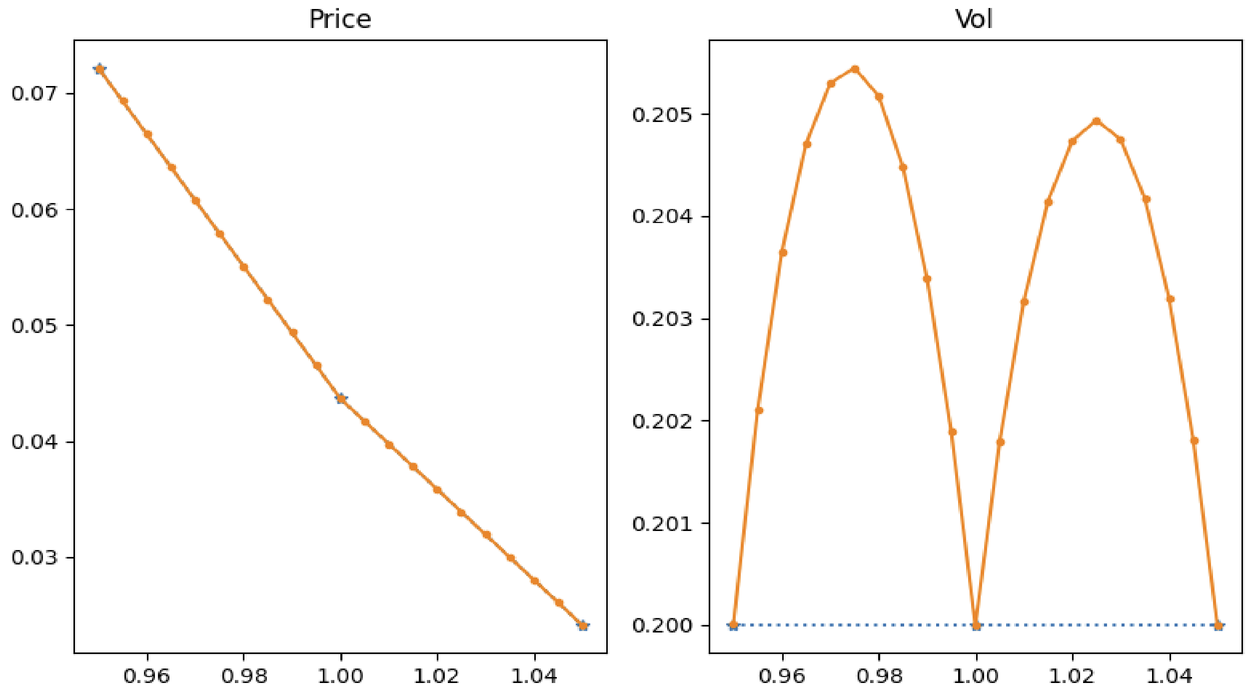
- Stochastic Volatility Inspired SVI [1]
  - Great result – gives a simple, fast, parametrization of implied volatility which is arbitrage-free
  - It is parametric – so does not fit everything.

[1] Arbitrage-free svi volatility surfaces, Gatheral et al, 2014

Motivation

Historic Perspective

- Linear Price Fit [1] ← which we will discuss
  - Actually does everything except being smooth.
  - It is “too expensive” – graph shows effect on implied volatility of linear interpolation of call prices themselves priced at 20% implied vol



[1] Hans Buehler. Expensive martingales. Quantitative Finance, 6(3):207–218, 2006.

Motivation

	Smooth	Arbitrage-Free	Perfect fit	Complexity
Model based: Heston etc with particle local vol	√	√	√	**High**
Implied vol parametric: SABR, Vanna-Vola, etc	√	**X**	√	Low
Implied vol Splines etc.	√	**X**	√	Low
SSVI	√	√	**X**	Low
Linear	**X**	√	√	Linear
SANOS	√	√	√	**Linear**

Gatheral and Jacquier [1]: "Prior work has not successfully [… eliminated] static arbitrage and indeed, efforts to find simple closed-form arbitrage-free parameterizations of the implied volatility surface are still widely considered to be futile."

[1] Arbitrage-free SVI volatility surfaces, Gatheral, Jacquier https://arxiv.org/pdf/1204.0646 2013ff

Markets with Dividends and Drift

Notation

- All market strikes are normalized, i.e. if F_T and DF_T are the forward and discount factor for some expiry T, and if $\tilde{C}$ is the price of a call with strike $\widetilde{K}$ then

$$C(T,K) := \frac{\tilde{C}(T,\widetilde{K})}{DF_T F_T}$$

  is the normalized call price for the normalized strike $K := \widetilde{K}/F_T$.
- Apply this to both bid and ask (this presumes that spot has negligible bid/ask).
- This method implicitly assumes that dividends are proportional; see [1] on how to consistently incorporate cash dividends.

- We will generally have two sets of strikes an expires:
  - Normalized market strikes and expiries will be K and T, respectively.
  - Model strikes and expiries will be k and τ, respectively.

[1] Volatility and Dividends, Buehler 2007, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1141877

Notation

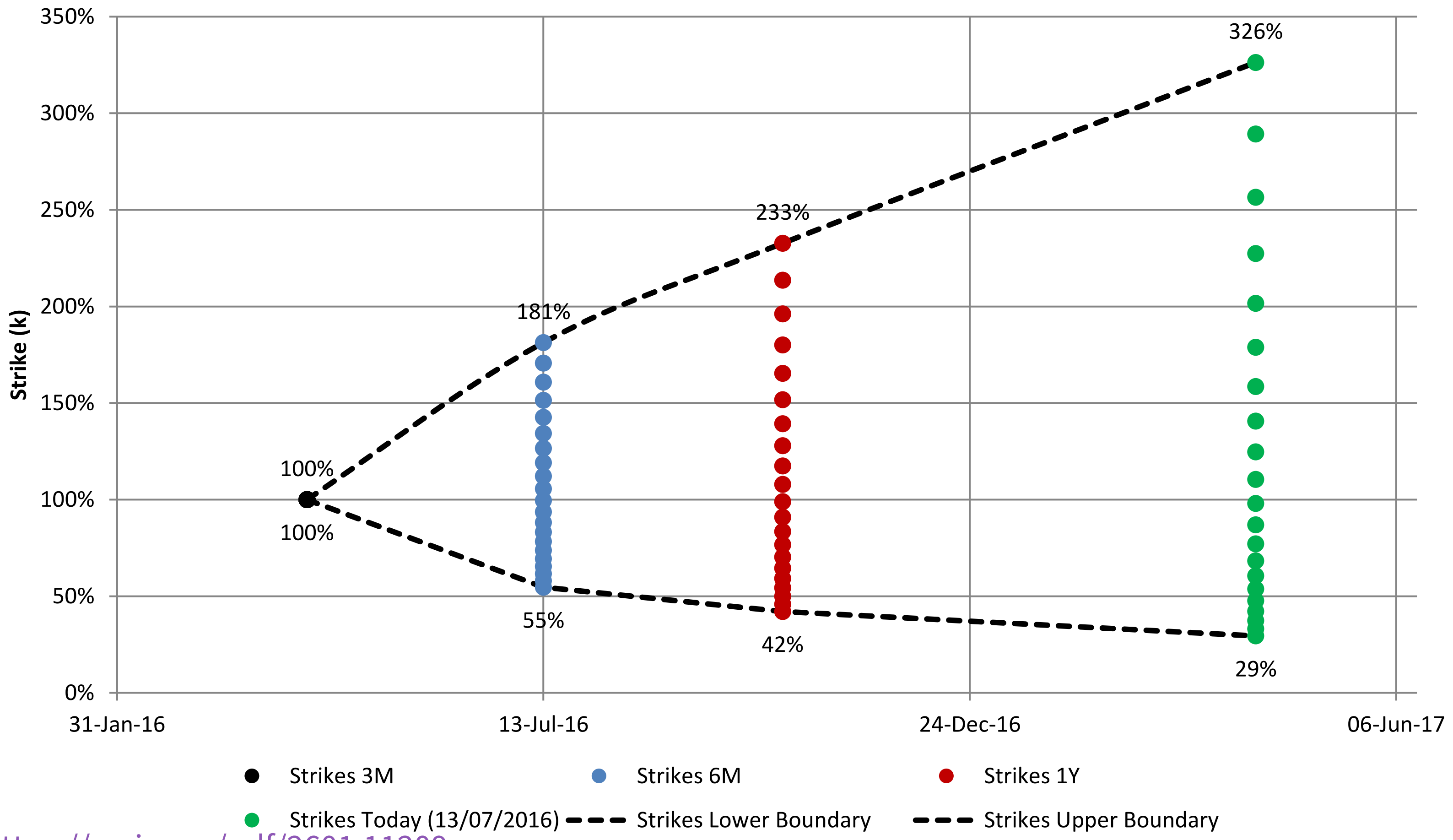
- A specific market will be given by
  - **Expiries** $0 < T_1 < \cdots < T_M$
  - Normalized **strikes** K_j with $0 < K_j^1 < \cdots 1 \cdots < K_j^{N_j}$ for each expiry.
  - **Bid** and **ask** prices B_j^i and A_j^i for $i = 2, \dots, N_j - 1$ satisfy $B_j^i \geq 0$ and $A_j^i \geq B_j^i + e$ where $e > 0$ is the **minimum tick size** (typically 0.01$ in the US)
  - At **boundary strikes** we assume w.l.g. they are at intrinsic value, i.e.

$$A_j^1 = B_j^1 = 1 - K_j^1 \quad \text{and} \quad A_j^{N_j} = B_j^{N_j} = 0.$$

  - We also define
    - The **mid price** $M_j^i := \frac{1}{2}(A_j^i + B_j^i)$
    - The **half spread** $\gamma_j^i := \frac{1}{2}(A_j^i - B_j^i)$

Notation

- Assume that the strike range is widening i.e. $K_j^1 \geq K_{j+1}^1$ and $K_j^{N_j} \geq K_{j+1}^{N_{j+1}}$ (can always be achieved, c.f. [1])



[1] Buehler et al, 2026 SANOS https://arxiv.org/pdf/2601.11209

Absence of Static Arbitrage

Absence of Arbitrage

Definition

- We start with classic notions of no-arbitrage without bid/ask.
- Let $C(T, K)$ be a continuous normalized call price function for $T \geq 0$ and $K \geq 0$. We say C is **free of arbitrage** if there exists a martingale X under some measure P such that

$$C(T, K) = \mathrm{E}[(X_T - K)^+]$$

- This aligns with the “no free lunch” paradigm of the first fundamental theorem of asset pricing.

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Theorem [1]:

- C is free of arbitrage if and only if
  - $C(T,0) = 1$, $\lim_{K\uparrow\infty} C(T,K) = 0$,
  - $C(T,\cdot)$ is non-increasing with $\partial_K C(T,0) \in [-1,0)$, (*)
  - $C(T,\cdot)$ is convex, and
  - $C(\cdot,K)$ is non-decreasing.
  - $C(0,K) = (1-K)^+$
- Moreover, $X > 0$ if and only if $\partial_K C(T,0) = -1$.

Proposition: above conditions are minimal [1]:

- In particular, $\partial_K C(T,K) \leq 0$ and $\partial_{KK} C(T,K) \geq 0$ alone are not sufficient.
- On the flip side, $\partial_K C(T,K) \in [-1,0]$ and $C \geq \max\{1-K, 0\}$ follow from above.

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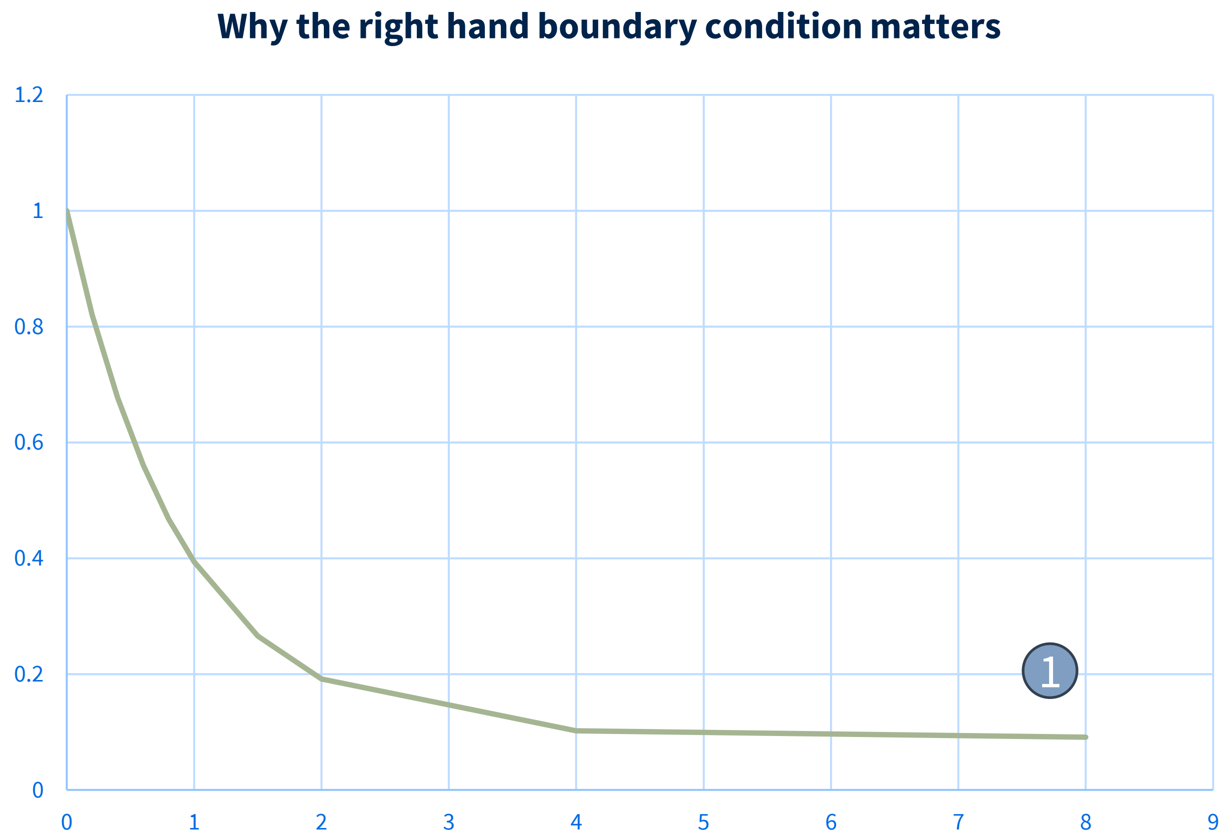
[1] Hans Buehler. Expensive martingales. Quantitative Finance, 6(3):207–218, 2006.

(*) All derivatives are right hand derivatives, e.g. $\partial_K C(T,K) \coloneqq \lim_{\epsilon\downarrow 0} \frac{1}{\epsilon}(C(T,K+\epsilon) - C(T,K))$

Strict Absence of Arbitrage

Absence of Arbitrage in Discrete Space and Time

Why $\lim_{K \uparrow \infty} C(T, K) = 0$ matters



Absence of Arbitrage

Definition

- Let C_j^i be discrete call prices for market expiries T_j with strikes K_j.
- We say C is **free of arbitrage** if there exists a (discrete) martingale X under some measure P such that

$$C_j^i = \mathrm{E}\left[\left(X_{T_j} - K_j^i\right)^+\right]$$

- We say a market with bid and prices B and A is **free of actionable arbitrage** if there exists arbitrage-free call prices such that $B_j^i \leq C_j^i \leq A_j^i$.

Absence of Arbitrage

Definition

- Let C_j^i be call prices for market expiries T_j with strikes K_j; w.l.g. we assume boundary strike call prices are equal to intrinsic.
  Extend its definition to $K_j^0 := 0$ with $C_j^0 = 1$ and define for $i = 0, \dots, N_k - 2$

$$dC_j^i := \frac{C_j^{i+1} - C_j^i}{K_j^{i+1} - K_j^i}$$

- Note that $dC_j^0 = -1$; also let $dC_j^{N_j} := 0$.

Linear Interpolation and SANOS

Theorem [1]:

- Let C_j^i be call prices for market expiries T_j with strikes K_j. Then C is arbitrage-free if and only if the linear interpolation of all call prices in space and time is free of arbitrage (as a continuous call price function).
- This is the case if:
  - call prices are convex: $dC_j^i \leq dC_j^{i+1}$ and
  - call price are increasing in time in linear interpolation in the sense that if $K_{j+1}^i \in \left[K_j^\ell, K_j^{\ell+1}\right)$:

$$C_{j+1}^i \geq \bar{C}_{j+1|j}^i := C_j^\ell \frac{K_j^{\ell+1} - K_{j+1}^i}{K_j^{\ell+1} - K_j^\ell} + C_j^{\ell+1} \frac{K_{j+1}^i - K_j^\ell}{K_j^{\ell+1} - K_j^\ell}$$

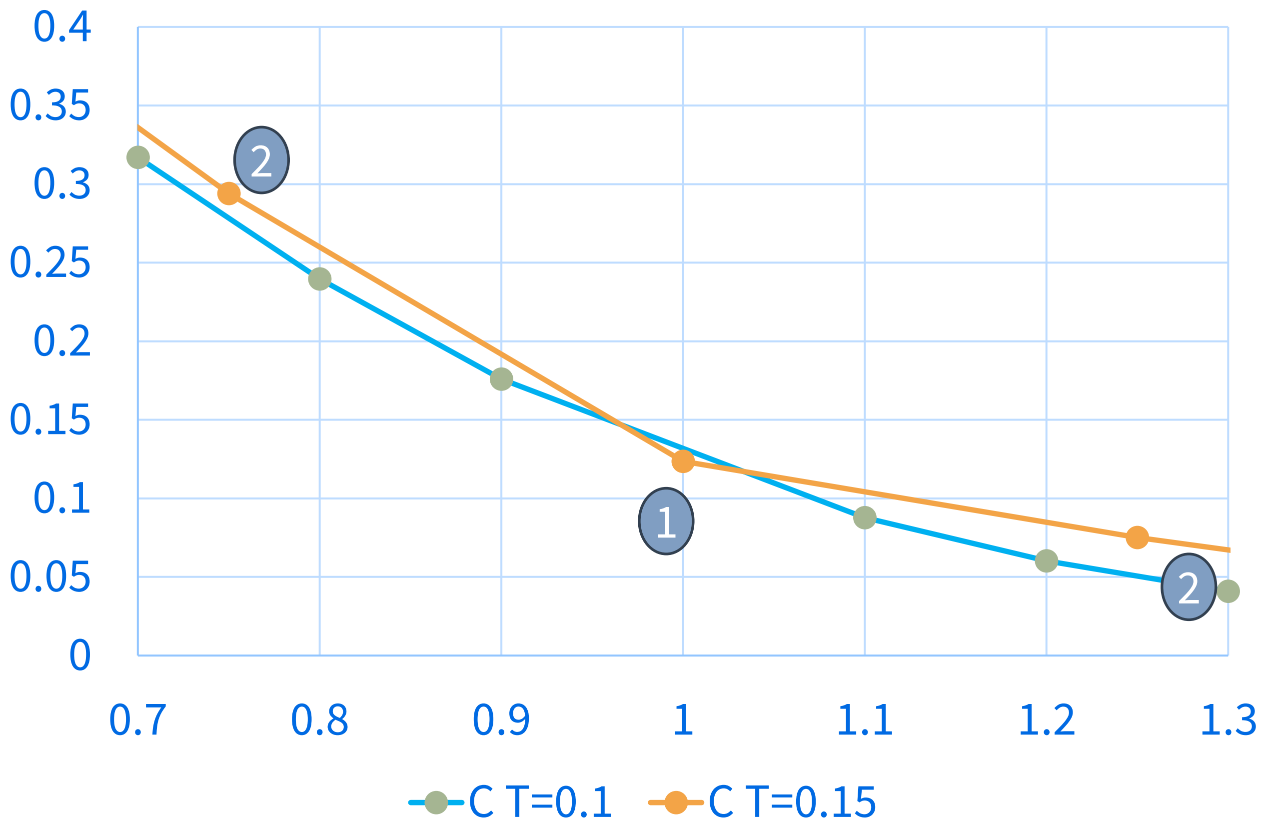
- The process X is positive if and only if $dC_j^0 = -1$ which implies $C_j^1 = 1 - K_j^1$.

[1] Hans Buehler and Evgeny Ryskin. Discrete local volatility for large time steps(extended version). https://papers.ssrn.com/abstract=2642630 2015.

Strict Absence of Arbitrage

Why do we impose:

$$C_{j+1}^{i} \geq \bar{C}_{j+1|j}^{i} \coloneqq C_j^{\ell} \frac{K_j^{\ell+1} - K_{j+1}^{i}}{K_j^{\ell+1} - K_j^{\ell}} + C_j^{\ell+1} \frac{K_{j+1}^{i} - K_j^{\ell}}{K_j^{\ell+1} - K_j^{\ell}}$$



Linear Interpolation and SANOS

Proposition [1]:

- Under the conditions of the previous theorem a necessary condition can be achieved if we extend the inner strikes iterative at follows:
  Set $\overline{K}_M := K$ and then
  $$\overline{K}_{\boldsymbol{j}} := K_j \cup \left\{ \overline{K}^i_{j+1} \colon K^2_j \le \overline{K}^i_{j+1} \le K^{N_j}_j \right\}$$
- Then for each strike $\overline{K}^i_{j+1}$ there is a corresponding ℓ such that $\overline{K}^\ell_j = \overline{K}^i_{j+1}$ and the condition becomes

$$C^i_{j+1} \ge C^\ell_j$$

- In this case the market is free arbitrage if and only if our conditions hold.

[1] Hans Buehler and Evgeny Ryskin. Discrete local volatility for large time steps(extended version). https://papers.ssrn.com/abstract=2642630 2015.

Linear Interpolation and SANOS

- Assume the conditions of the theorem are met. Then [1] there exists a discrete state and space martingale X defined under some measure P such that

$$C_j^i = \mathrm{E}\left[\left(X_{T_j} - K_j^i\right)^+\right]$$

- Its marginale martingale densities $p = (p_1, \dots, p_M)$ are given by

$$p_j^i := dC_j^{i+1} - dC_j^i$$

- In [1] we also construct transition matrices between marginals, and show how to consistently use small time steps between expiries.

[1] Hans Buehler and Evgeny Ryskin. Discrete local volatility for large time steps(extended version). https://papers.ssrn.com/abstract=2642630 2015.

Linear Arbitrage-Free Fitting

Linear Arbitrage-Free Fitting

- Objective: Find Arbitrage-Free Option Surfaces
  - Find discrete arbitrage-free call prices within bid/ask or as good as possible
  - Often arbitrage in data is a data issue not a real opportunity.

Linear Arbitrage-Free Fitting

Definition

- We now define absence of arbitrage in the presence of bid/ask prices.
- Let B_j^i and A_j^i be market bid and ask prices expiries T_j and inner strikes $K_j^2, \dots, K_j^{N_j - 1}$.
- We say **the market is free of arbitrage** if there exists positive arbitrage-free call prices C_j^i between bid/ask, i.e. $B_j^i \leq C_j^i \leq A_j^i$.

- In that case let δ_j^i be a trade in all options, with $\delta_k^i > 0$ indicating we want to buy the option with expiry T_j and strike K_j^i. Then the PnL of δ

$$\Pi(\delta) = \sum_{i,j} \delta_j^i \left\{ \left(X_{T_j} - K_j^i \right)^+ - M_j^i \right\} - \left| \delta_j^i \right| \gamma_{jk}^i$$

which cannot be non-negative with positive expectation (i.e. an actionable arbitrage).

Linear Arbitrage-Free Fitting

- We start with a candidate martingale density $q = (q_1, \dots, q_M)$ where $q_j \in R^{n_j}$.
- Being a density means
  - $q_j \geq 0$
  - $q_j' 1 = 1$
- Being a marginal for a martingale with unit mean means
  - $q_j' K_j = 1$
- Being a martingale density is ensured if
  - $C_j \geq \bar{C}_{j|j-1}$

Linear Arbitrage-Free Fitting

- We start with a candidate martingale density $q = (q_1, \dots, q_M)$ where $q_j \in R^{n_j}$.
- Being a density means: $q_j \geq 0, q_j' 1 = 1$
- Being a marginal for a martingale with unit mean means: $q_j' K_j = 1$
- Being a martingale density is ensured if: $C_j \geq \bar{C}_{j|j-1}$
- We note that C_j is a linear function of q_j, and $\bar{C}_{j|j-1}$ is a linear function of q_{j-1}:

$$C_j^{\cdot} \equiv \Xi_j p_j := \sum_{\ell=1}^{N_j} \left(K_j^{\ell} - K_j^{\cdot}\right)^+ q_j^{\ell}$$

$$\bar{C}_{j|j-1}^{\cdot} \equiv L_{j-1} p_{j-1} := \sum_{\ell=1}^{n_j} \left(K_{j-1}^{\ell} - K_j^{\cdot}\right)^+ q_{j-1}^{\ell}$$

Linear Arbitrage-Free Fitting

Fit as close as possible to Bid/Ask [1]

- Find

$$\inf_q : \sum_j w_j \left\{ \left(C - A_j\right)^+ + \left(B_j - C_j\right)^+ + \epsilon |C_j - M_j| \right\}$$

  subject to the linear constraints

  - $q_j \geq 0$
  - $q_j' 1 = 1$
  - $q_j' K_j = 1$
  - $C_j \geq \hat{C}_{j|j-1}$

- The program for $\epsilon = 0$ has a solution within bid/ask if and only if the market is arbitrage free.

[1] Hans Buehler and Evgeny Ryskin. Discrete local volatility for large time steps(extended version). https://papers.ssrn.com/abstract=2642630 2015.

Linear Arbitrage-Free Fitting

Fitting within Bid/Ask [1]

- Find

$$\inf_q : \sum_j w_j |C_j - \widetilde{C}_j|$$

  subject to the linear constraints

  - $q_j \geq 0$
  - $q_j' 1 = 1$
  - $q_j' K_j = 1$
  - $C_j \geq \hat{C}_{j|j-1}$
  - $C_j \leq A_j, C_j \geq B_j$

- The program has a solution only if the market is arbitrage free.

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[1] Samuel N. Cohen, Christoph Reisinger, and Sheng Wang. Detecting and repairingarbitrage in traded option prices. Applied Mathematical Finance, 27(5):345–373,2020.

Linear Arbitrage-Free Fitting

Extension (beyond the scope of this talk)

- We can impose existence of a bounded local volatility as linear constraint: essentially "Discrete Local Vol" $\Sigma_j \in R^{N_j - 2}$ is defined as the solution to

$$C_j - \bar{C}_{j|j-1} = \frac{1}{2}\Sigma^2 K^2 \ \Gamma C_j$$

  where Γ is a linear operator (taking second differences of C_j), c.f. [1].
- The paper [1] discusses how to
  - Define PDE and Monte-Carlo methods which are 100% consistent with q.
  - How to take small time steps which are consistent with q.
  - How to apply similar ideas to mean-reverting processes.

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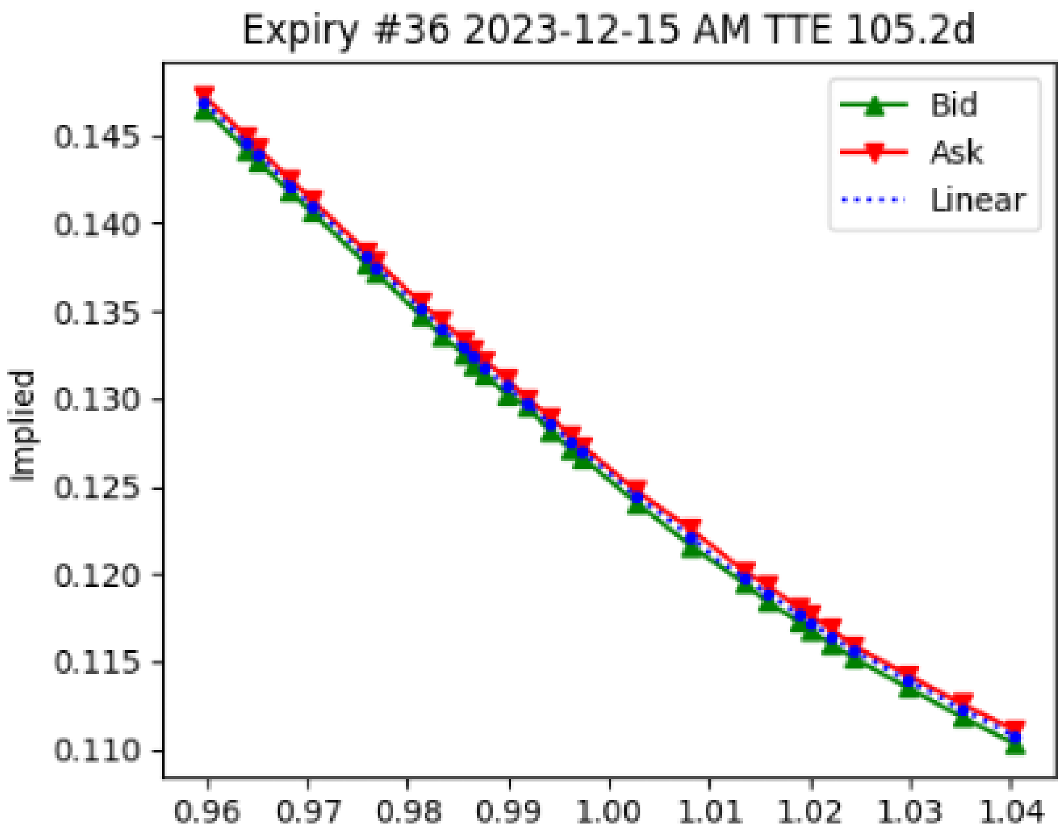
[1] Hans Buehler and Evgeny Ryskin. Discrete local volatility for large time steps(extended version). https://papers.ssrn.com/abstract=2642630 2015.

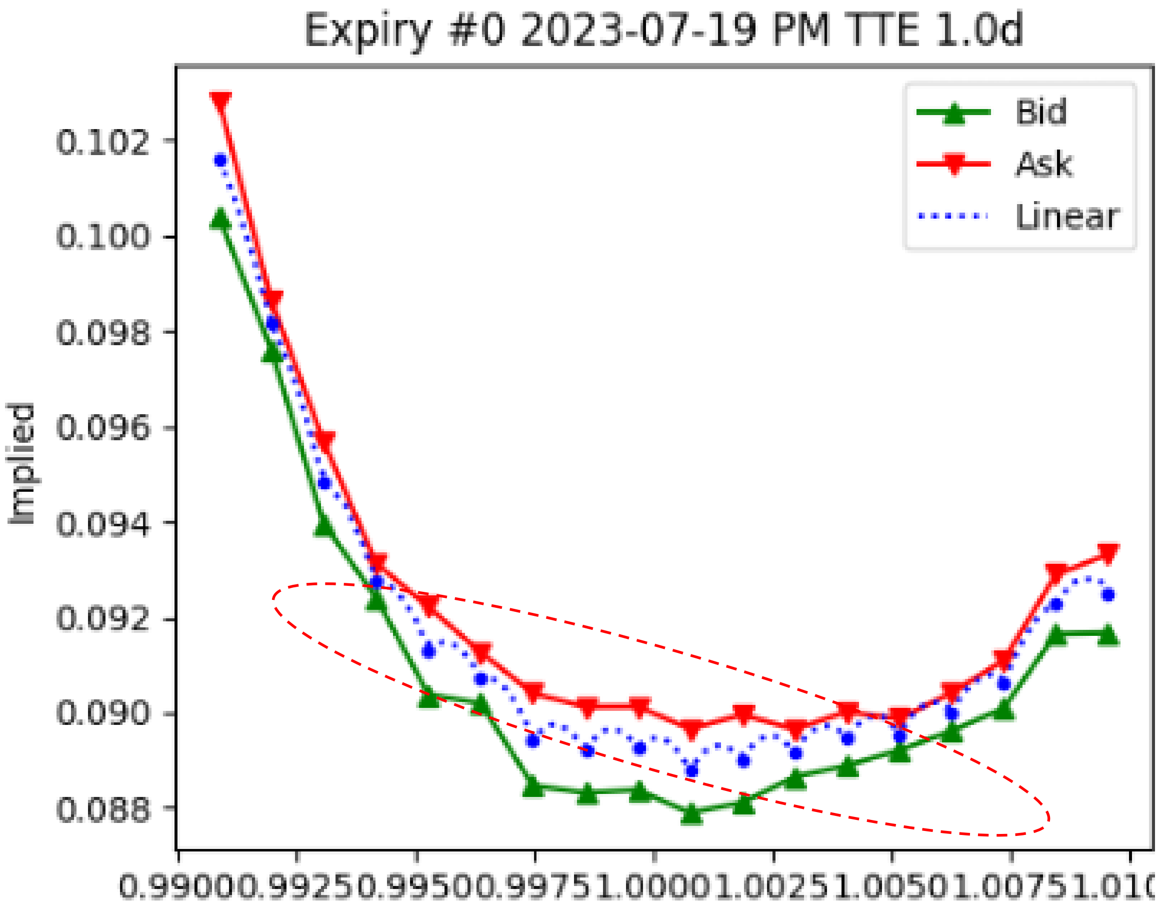
Linear Arbitrage-Free Fitting

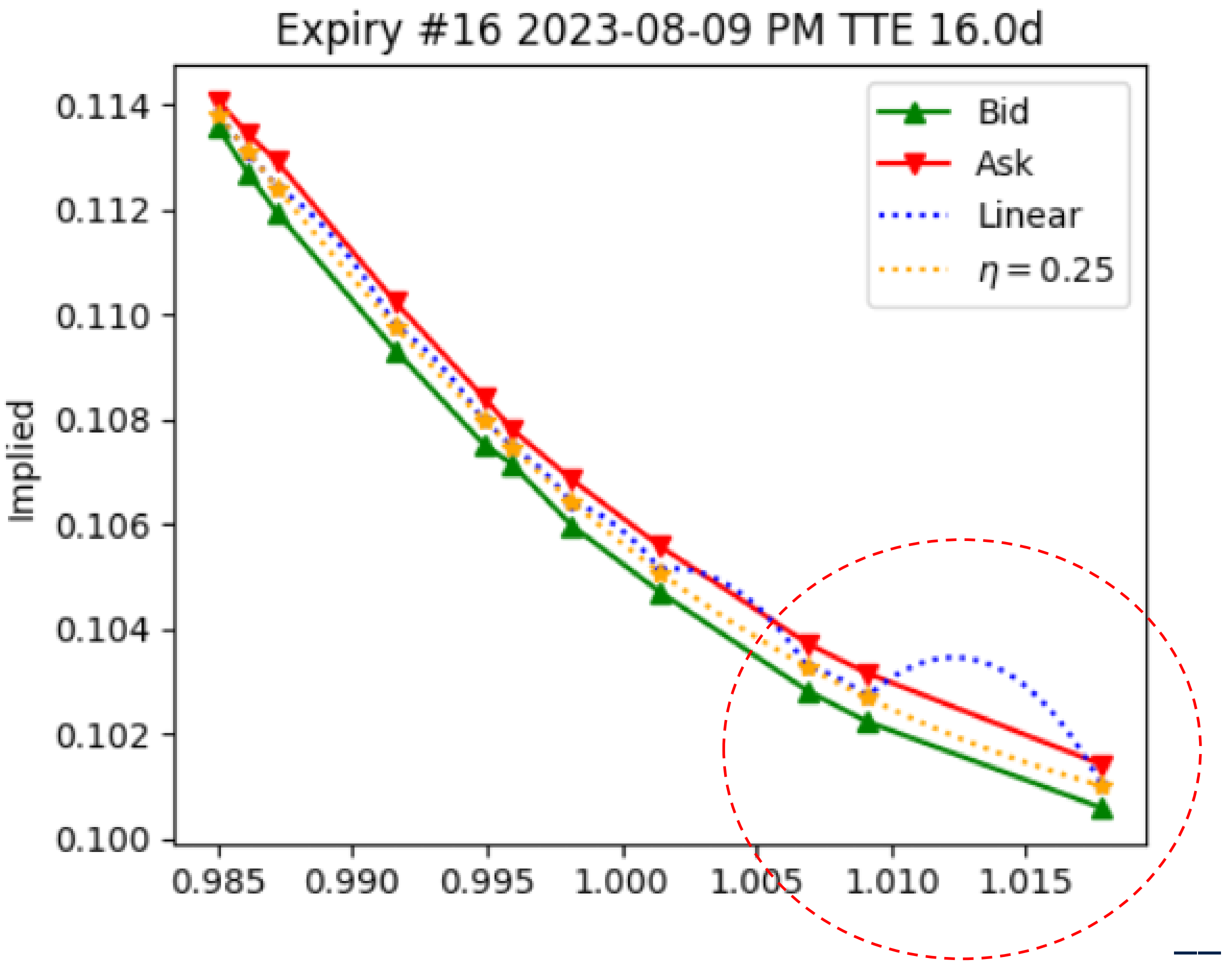
- Fitting SPX 2023-07-18 fore over 1,400 options in 3s is “perfect”…



Linear Arbitrage-Free Fitting

- But … linear interpolation is “too expensive”.





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Strictly Arbitrage-free Non-parametric Option Surfaces

SANOS

- Recall the linear interpolation scheme for any martingale density q as:

$$C_j^{\cdot} \equiv \Xi_j p_j := \sum_{\ell=1}^{N_j} \left(K_j^{\ell} - K_j^{\cdot}\right)^{+} q_j^{\ell}$$

- SANOS basic idea: make this smooth by using a martingale Y and defining, per expiry,

$$C(T_j, K) := \sum_{\ell=1}^{N_j} E\left[\left(Y_{T_j} K_j^{\ell} - K\right)^{+}\right] q_j^{\ell}$$

- Obviously smooth in K.
- Similar base architecture to [1] who uses different BS martingales per strike (this means losing easy control over term structure arbitrage).

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[1] Volatility surfaces and log-normal mixture: Crafting an arbitrage-free calibration, 2025, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4602237

SANOS

- Basic idea: make this smooth by choosing a martingale Y and defining

$$C^{\cdot}_j \equiv \Xi_j p_j := \sum_{\ell=1}^{N_j} E\left[\left(Y_{T_j} K_j^\ell - K\right)^+\right] q_j^\ell$$
$$\bar{C}^{\cdot}_{j|j-1} \equiv L_{j-1} p_{j-1} := \sum_{\ell=1}^{n_j} E\left[\left(Y_{T_{j-1}} K_{j-1}^\ell - K^{\cdot}_j\right)^+\right] q_{j-1}^\ell$$

- If Y is a martingale and q are martingale density marginals then

$$C_j \geq \bar{C}_{j|j-1}$$

- However, notice that if q are the linear marginal densities then the prices with Y are strictly above those of q, that means we no longer fit the market if we use the same density q c.f. [1]

[1] Volatility surfaces and log-normal mixture: Crafting an arbitrage-free calibration, 2025, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4602237

SANOS

- Putting it together
  - Interpolating in time
  - Separating the expiries/strikes in the model from the market expiries/strikes.
  - Show fitting is still linear programming – but the result is smooth.

SANOS

SANOS

- Let $0 < \tau_1 < \cdots < \tau_{\mathrm{m}}$ be *model* expiries with *model* strikes $0 < k_j^1 < \cdots 1 \cdots < k_j^{n_j}$.
- Let $V(t)$ be a variance curve (e.g. ATM variance) and $\eta \geq 0$ a smoothing parameter.
- Assume that $q_1, \ldots, q_M$ is a sequence of martingale densities over the model strikes.
- Finally assume $\alpha_j(T) \coloneqq (T - \tau_{j-1})/(\tau_j - \tau_{j-1})$ or a smoother version thereof.
- Define then

$$C(T, K) \coloneqq \begin{array}{l} \alpha_j(T) \displaystyle\sum_{i=1}^{N_j} q_j^i \, BSCall\left(k_j^i, K, \eta V(T)\right) + \\ (1 - \alpha_j(T)) \displaystyle\sum_{i=1}^{N_{j-1}} q_{j-1}^i \, BSCall\left(k_{j-1}^i, K, \eta V(T)\right) \end{array}$$

- Smooth version of the linear case $\eta = 0$.

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- SANOS provides a smooth, strictly arbitrage-free option surface interpolation.

$$C(T,K) := \begin{matrix} \alpha_j(T) & \sum_{i=1}^{N_j} q_j^i \, BSCall\left(k_j^i, K, \eta V(T)\right) + \\ (1-\alpha_j(T)) & \sum_{i=1}^{N_{j-1}} q_{j-1}^i \, BSCall\left(k_{j-1}^i, K, \eta V(T)\right) \end{matrix}$$

- Direct proof [1] :
  - $C(T,\cdot) \in C^\infty$ for all $\eta > 0$
  - $C(\cdot, K)$ is as smooth as α and V are. Using monotone splines makes it C^1.
  - Being a convex sum of arbitrage-free operators means C is arbitrage-free; main step is to prove that $C\left(\tau_j, K\right) \geq C\left(\tau_{j-1}, K\right)$.

[1] Buehler et al, 2026 SANOS https://arxiv.org/pdf/2601.11209

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- Let Y be the log-normal process with variance ηV. Then

$$C(\tau_j, K) := \sum_{i=1}^{n_j} \mathrm{E}\left[\left(Y_j\, k_j^i - K\right)^+\right] q_j^i \geq \sum_{i=1}^{k_j} \mathrm{E}\left[\left(Y_{j-1}\, k_j^i - K\right)^+\right] q_j^i = (*)$$

- Now we use the martingale property of q which means for any convex function f

$$\sum_{i=1}^{n_j} f\left(k_j^i\right) q_j^i \geq \sum_{i=1}^{n_{j-1}} f\left(k_{j-1}^i\right) q_{j-1}^i$$

indeed:

$$(*) = E\left[Y_{j-1} \sum_{i=1}^{n_j} \left(k_j^i - \frac{K}{Y_j} \right)^+ q_j^i \right] \geq E\left[Y_{j-1} \sum_{i=1}^{n_{j-1}} \left(k_{j-1}^i - \frac{K}{Y_{j-1}} \right)^+ q_{j-1}^i \right] = C(\tau_{j-1}, K)$$

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- In fact, the last step is a consequence of the observation that a time-discrete process which is consistent with C is

$$Z_j := Y_j X_j$$

where X is the time-and-space discrete process implied by q, independent of Y.

- Other processes such as Heston for Y are possible, but for our experiments so far log-normal seems to perform surprisingly well – but research continues.

Fitting SANOS to the Market

- Assume now we are given **market expiries** $0 < T_1 < \cdots < T_M$ with **market strikes** $0 = K_\ell^2 < \cdots 1 \cdots < K_\ell^{N_\ell - 1}$ with observed bids B_ℓ^i asks A_ℓ^i.
- We note that given $v_j := V(T_j)$ the model prices $C_\ell^i = C(T_\ell, K_\ell^i)$ are linear functions of the model martingale density q:

$$C(T,K) := \alpha_j(T) \sum_{i=1}^{N_j} q_j^i \,\mathrm{BSCall}\big(k_j^i, K, v_T\big) + (1 - \alpha_j(T)) \sum_{i=1}^{N_{j-1}} q_{j-1}^i \,\mathrm{BSCall}\big(k_{j-1}^i, K, v_T\big)$$

- We note that using model expires/strikes does not change that basic property.

Fitting SANOS to the Market

Fit as close as possible to Bid/Ask [1]

- Find

$$\inf_{q}: \sum_{j} w_j \left\{ \left(C - A_j\right)^+ + \left(B_j - C_j\right)^+ + \epsilon |C_j - M_j| \right\}$$

  subject to the linear constraints
  - $q_j \geq 0$
  - $q_j' 1 = 1$
  - $q_j' k_j = 1$
  - $C_j \geq \hat{C}_{j|j-1}$
- Same code base as the linear fit.
- The main change is the use of model expiries/strikes which is also applicable in the linear case.

[1] Buehler et al, 2026 SANOS https://arxiv.org/pdf/2601.11209

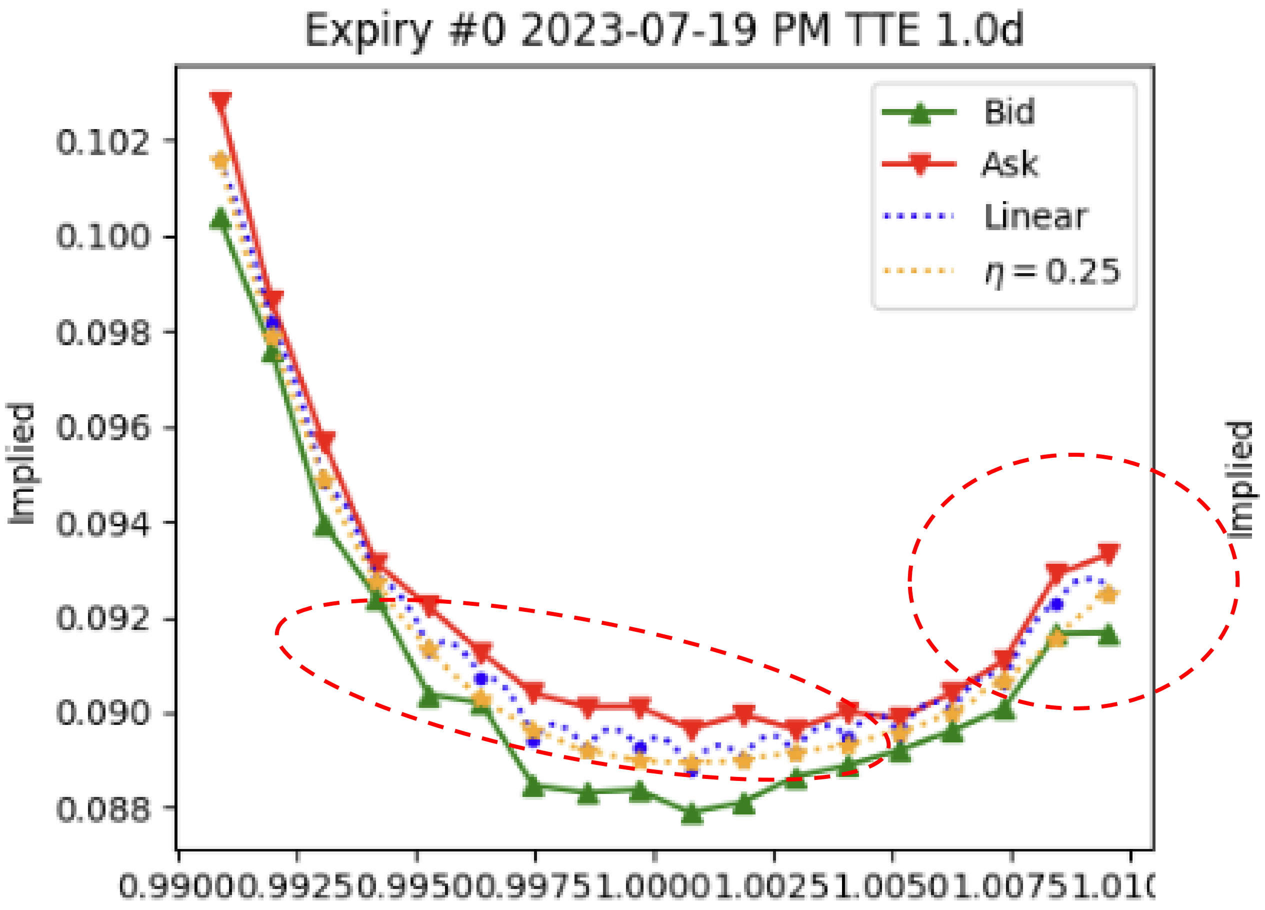
SANOS

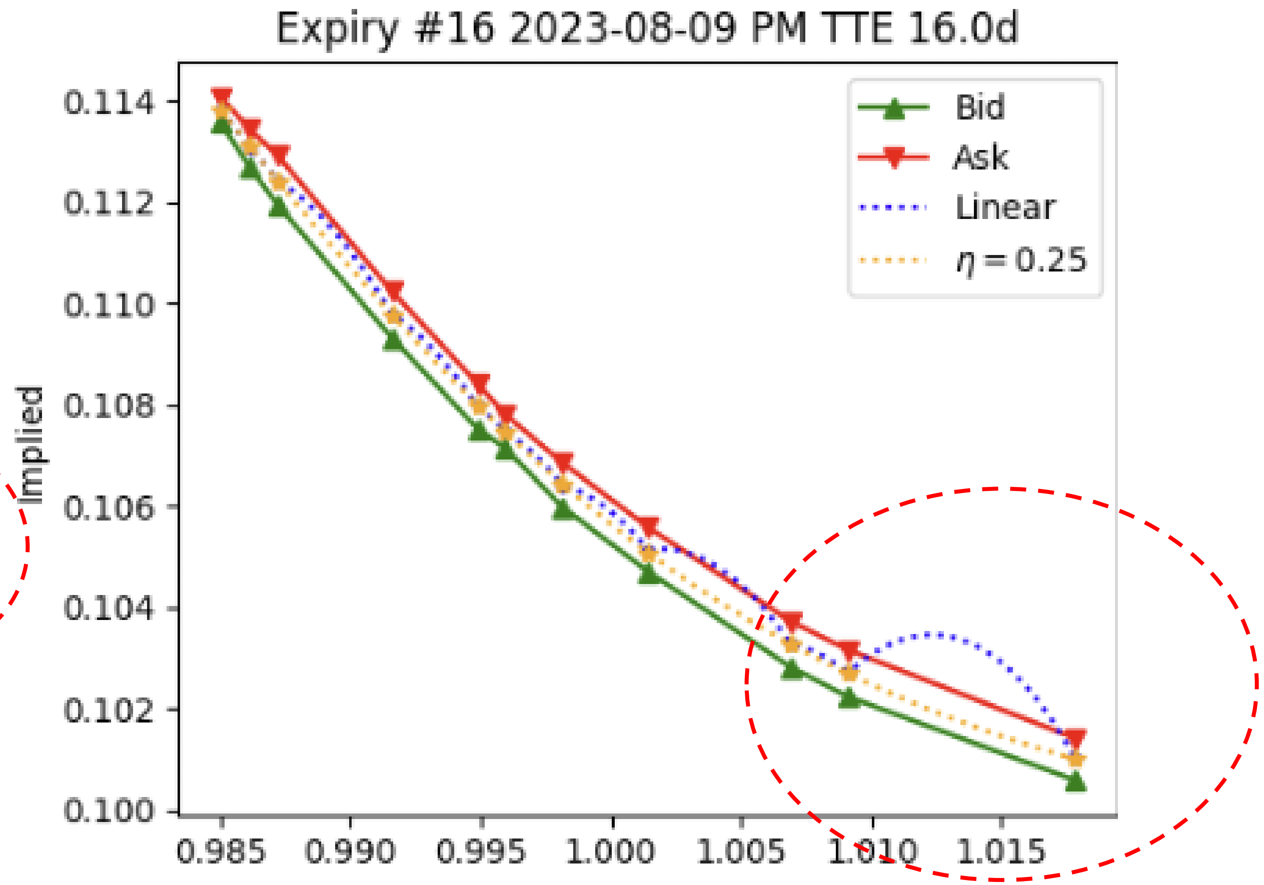
- **Proposition (Generality):** If the market is
  - Free of arbitrage,
  - **non-degenerate** in the sense that the linear density satisfies $p > 0$, and
  - the linear solution satisfies $C_j^i < A_j^i$
- then there exists some volatility $\varsigma > 0$ such that SANOS with $V_T := \varsigma^2 T$ and $q = p$ fits within bid-ask and is smooth.
- If the market is free of arbitrage, but degenerate, then SANOS can be reduced to its (non-smooth) linear fit.
- This is simply a consequence of

$$\sum_{i=1}^{N_j} \mathrm{BSC}all\left(K_j^i, K, \varsigma^2 T_j\right) p_j^i > \sum_{i=1}^{N_j} \left(K_j^i - K\right)^+ p_j^i$$

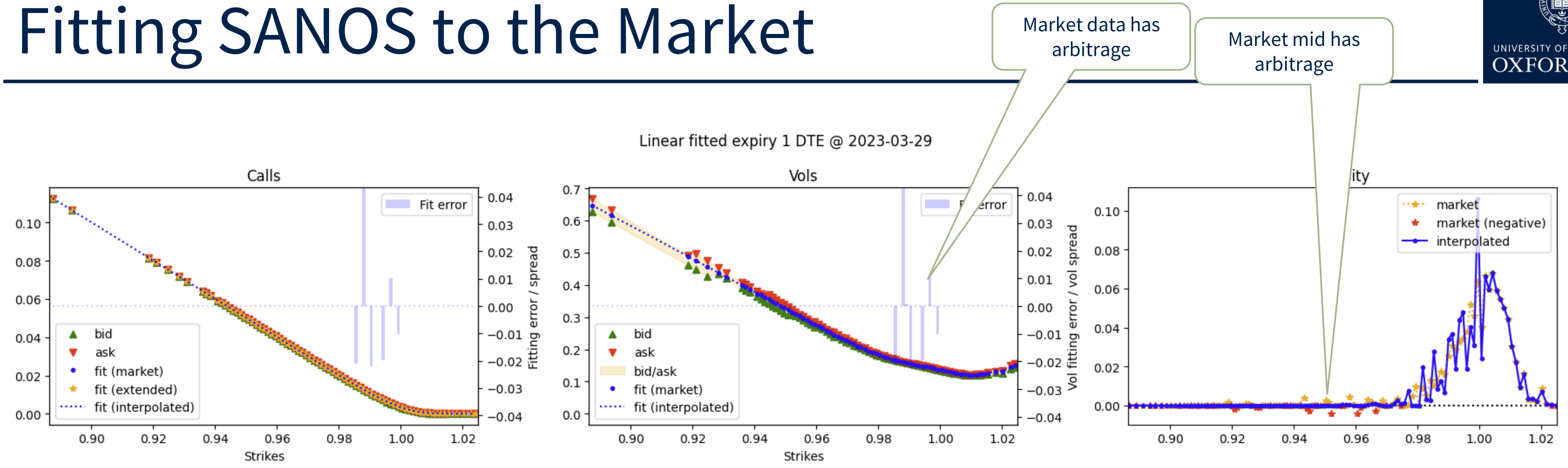
Linear Arbitrage-Free Fitting

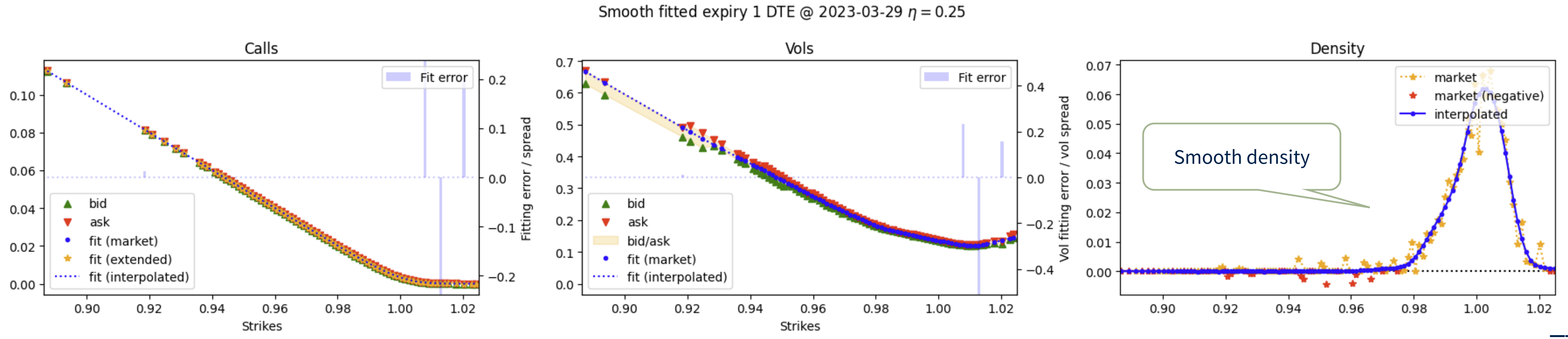
- Vs. linear interpolation is “too expensive” – previous example.



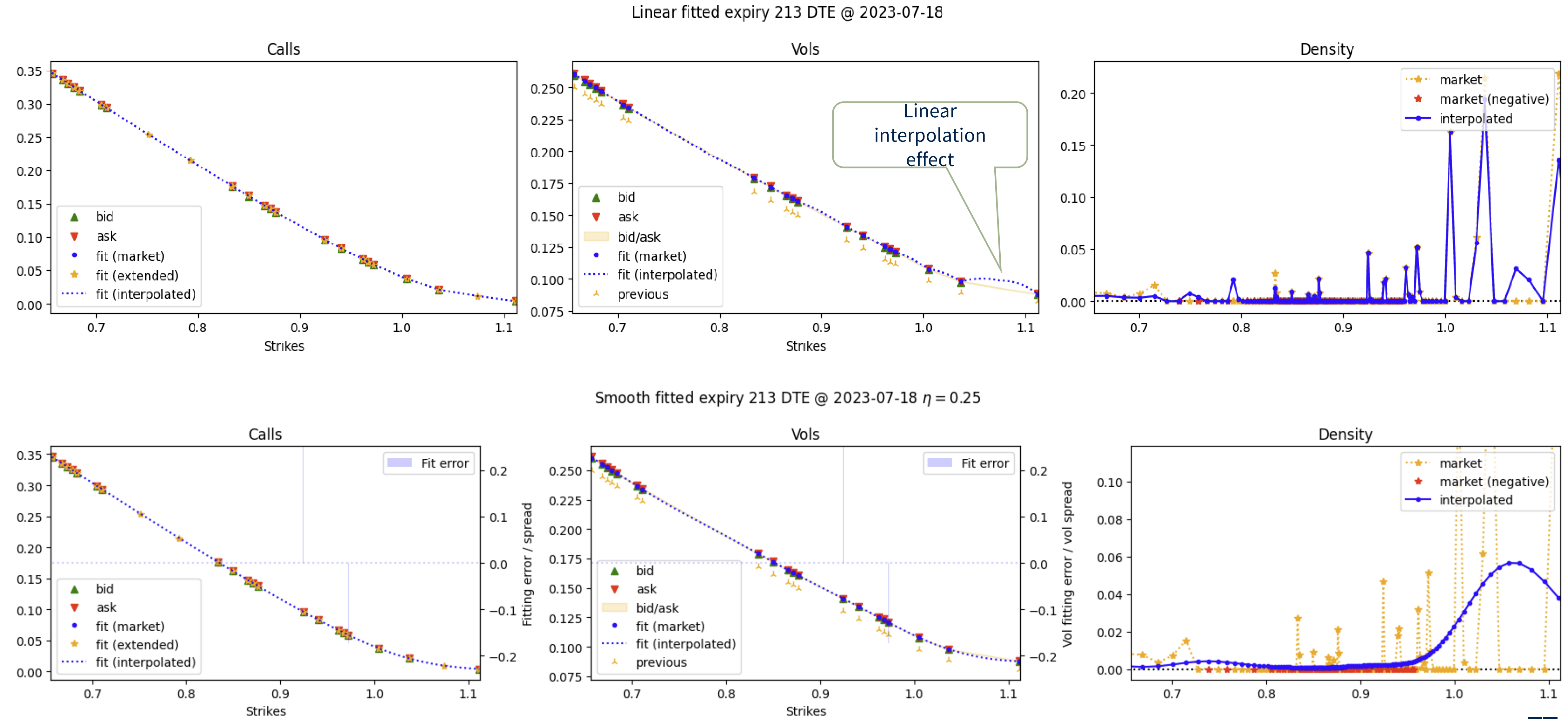


Fitting SANOS to the Market

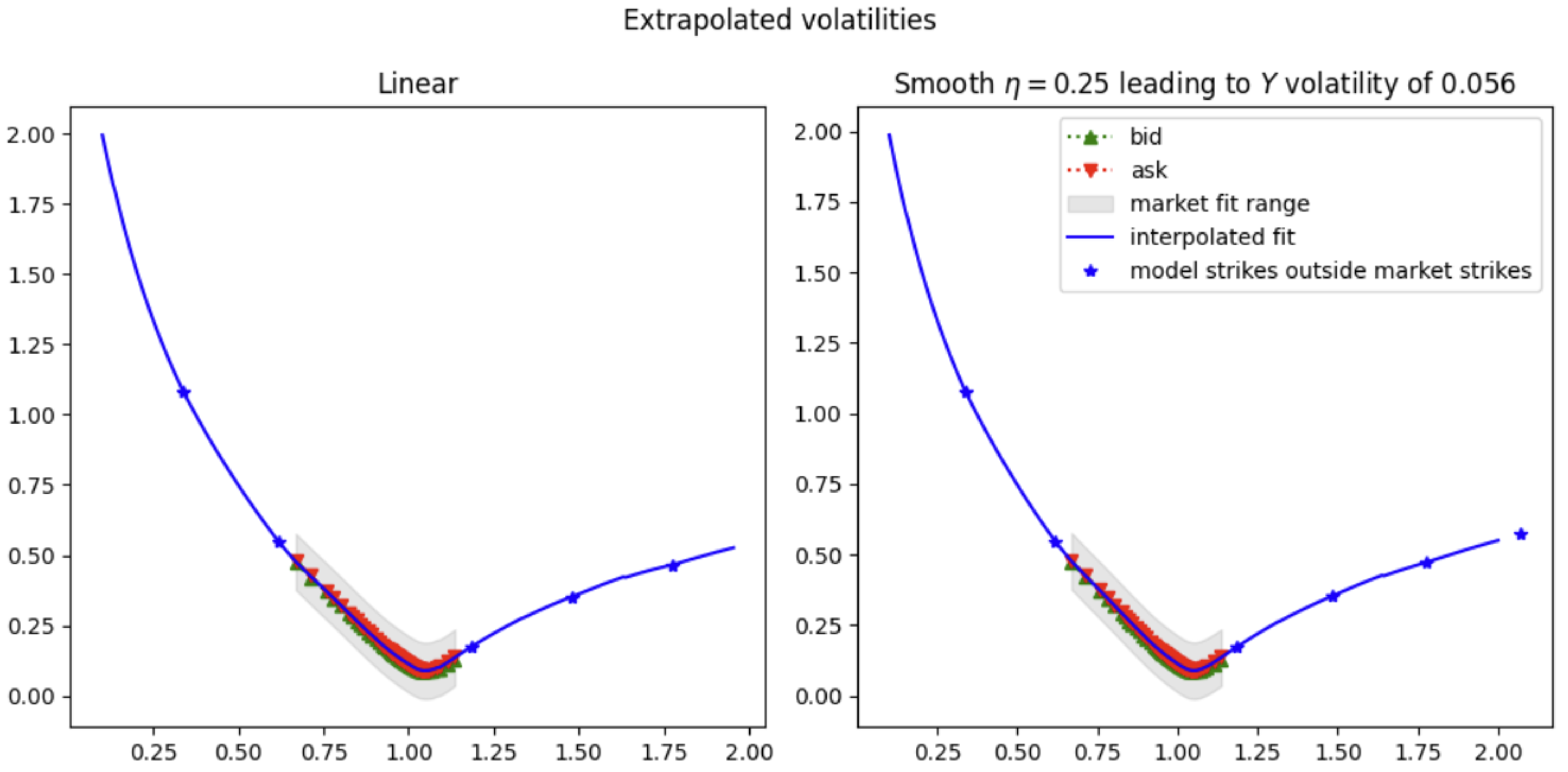




Fitting SANOS to the Market

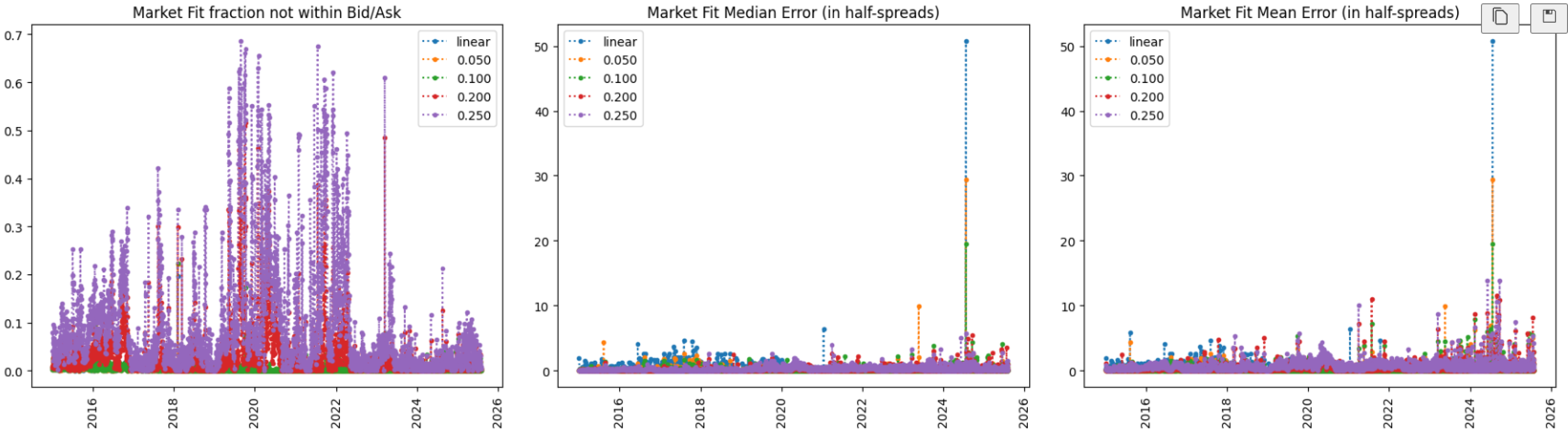


Fitting SANOS to the Market



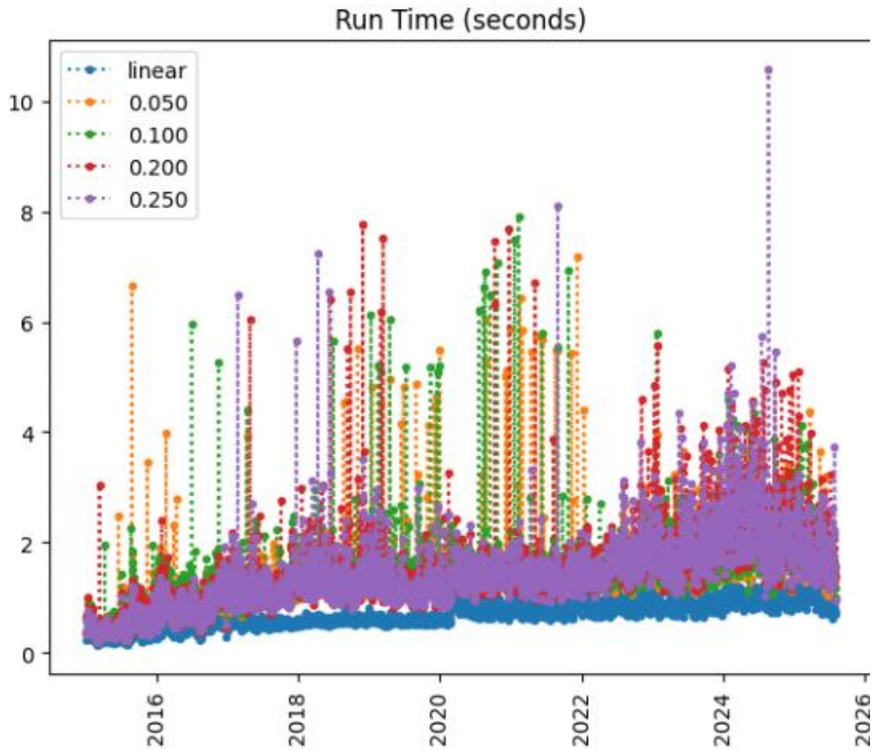
Fitting SANOS to the Market

- Fitting 1000 options within 2 ATM implied volatility standard deviations which had a Vega/sqrtT of at least 0.1% across expiries



Fitting SANOS to the Market

- Runtime a few seconds in Python/cvxpy



Fitting SANOS to the Market

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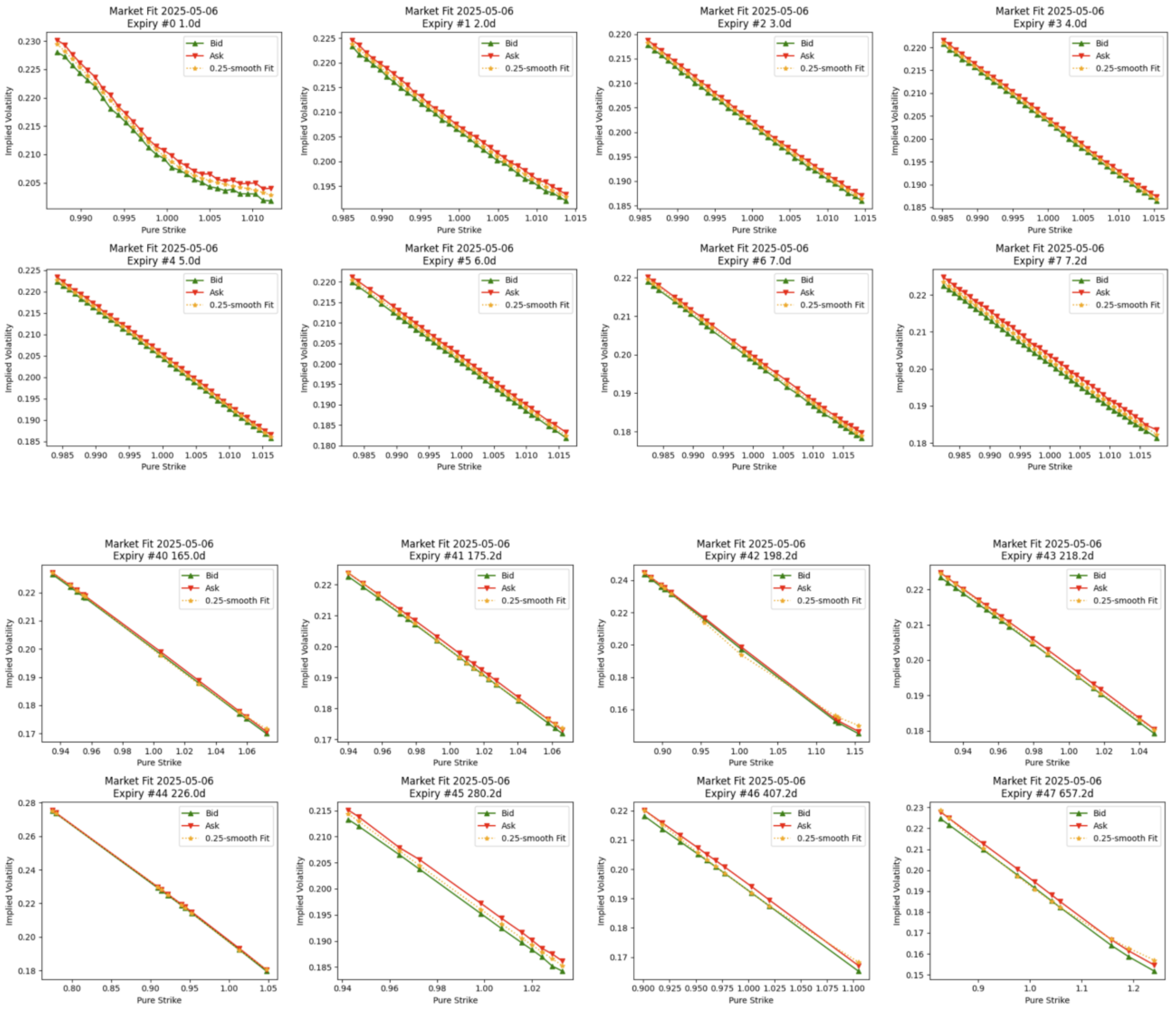

Fitted 1000 options within 2 ATM implied volatility standard deviations which had a Vega/sqrtT of at least 0.1% on 2025-05-06 across all 48 expiries from 1D to 657 business days.

Options were chosen by closeness to ATM. The model fitted 91.4% of all options within bid/ask. Of those options not fitted the median error is just 21% of half spread.

The fit took sub-seconds on a desktop PC.

Please ask questions

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