Systematic trading of options

Solving the volatility risk premium conundrum

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The advent of quantitative investing has made it increasingly important to understand the performance drivers of systematic strategies that use derivatives, such as those based on the sale of options. In this paper we introduce a new formulaic representation to analyse the performance of delta-hedged vanilla options and use this new formula to break down the historical performance of foreign exchange straddles held to maturity.

We show how, as is widely assumed, the performance is dictated in part by the so-called volatility premium, but also that another important driver is at play, the covariance effect between the convexity of the option and the prevailing volatility regime. Further, we determine empirically that the sign of that driver's contribution is tenor specific.

These results can be used to size directional or relative value option strategies and to disentangle the impact of the various performance drivers in the booming field of systematic options strategies.

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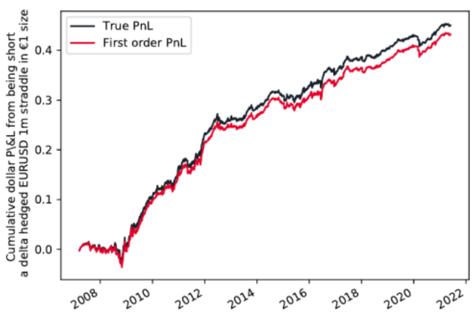
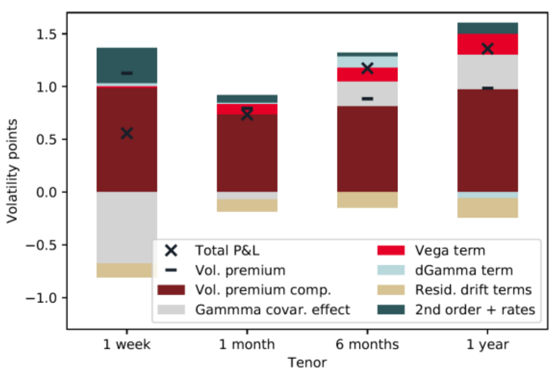


Source: SG Cross Asset Research, Bloomberg

... and splits performance into various components



Source: SG Cross Asset Research, Bloomberg

1. Solving the volatility risk premium conundrum

The challenges of systematic trading with options

Options pricing has traditionally been approached from the angle of the market maker or the risk manager. As a result, it focuses on calculating prices or instantaneous hedging ratios. By contrast, studies on the statistical properties of derivatives held over longer periods of time are less common. At the same time, the advent of quantitative investing has made it increasingly important to understand the performance drivers of systematic strategies which use derivatives, such as those based on the sale of options. The issue is all the more pressing since without a clear statistical framework, the science of strategy selection tends to rely excessively on back-tests, as argued in Lopez De Prado (2018).

Consider one of the most canonical examples of this kind of strategy: the systematic sale of straddles, i.e. of a call and a put, both struck at the money. It is commonly accepted that the cumulative returns from this kind of strategy arise from the difference between ex-ante implied volatility and ex-post realised volatility, a quantity known as the volatility premium. That intuition builds from the Black-Scholes formula, which states that when implied volatility is constant, the P& L of a delta-hedged options portfolio over a short time interval is proportional to gamma times implied minus realised volatility. But that heuristic is insufficient to explain the relationship between the option's performance and the volatility premium when the holding period is of arbitrary length, and when volatility isn't constant. For example, if one holds a delta hedge option until maturity, does it matter what implied volatility does along the way? Or is the performance related solely to the volatility premium?

Vol premium and trading performance – what we know

The study of option performance is at the crossroads of two areas of research: risk premium in the options market on the one hand, and pricing theory for risk management and P&L explanation purposes on the other.

On average, the volatility premium is positive: implied volatility tends to be higher than realised volatility, as observed in Carr & Wu (2009) for example. Options can be thought of as insurance contracts, and option buyers are willing to pay a premium versus fair value in exchange for protection in an adverse market environment. That source of risk premium has been the subject of many studies over the years, both from a modelling and from an empirical standpoint. Bakshi & Kapadia (2003) and later Hu & Jacobs (2020) found the volatility premium to be positively correlated with the level of volatility, and in Carr & Wu (2015), the authors introduced a model of implied volatility able to match the surface of option prices while allowing for a non-zero premium. Recent empirical studies include Fritzsch, Irresberger, & Weiß (2021), which uses machine learning techniques to flag outliers in the relationship between implied and realised volatility and monetise these dislocations. The topic is also of keen interest to banking and asset management practitioners. Société Générale Cross-Asset Quant Research (2017, p.180), for example, explores the possibility that the level of volatility premium correlates with future options returns.

Several tools have been developed to analyse the performance of vanilla options and to understand the impact and interplay between the underlying drivers. Ahmad & Wilmott (2005) measure the impact of the choice of delta hedging methodology, and more specifically of the volatility parameter in the delta calculation. The end goal there is to choose a measure of volatility that will maximise performance. By contrast, our aim is to analyse performance when holding an option over an arbitrary period of time, delta hedging using the live implied volatility. Bergomi (2016, p.180) studies the interplay between the changes in value that arise from changes in implied volatility and those that are due to the passage of time. Here the author is interested in timer options, i.e. options which expire once a given target of realised volatility has been reached. Even though his aim is different from ours, some of the arithmetic involved in his calculations also appears in our study.

To the best of our knowledge, our results are novel, both from a theoretical and an empirical standpoint. They do not appear in the literature mentioned above, or in specialised surveys like James, Fullwod, & Billington (2015).

A novel approach to performance attribution

Using traditional pricing tools, and making no assumptions on the dynamics of the underlying, we study the performance of systematic options strategies from a statistical angle, looking to isolate the main drivers.

Starting with the generic P& L formula for an options portfolio over an infinitesimal amount of time, we rewrite the equation to disentangle the transfers between the P&L coming from gamma and vega. This new generic equation includes a pure gamma P&L term, which involves the traded implied volatility rather than the live implied volatility, and a vega P&L term which adds noise but which sums up to zero over life of the option. This last fact confirms our intuition that moves in implied volatility add mark-to-market noise, but do not add much to the final performance.

Using foreign exchange as a test bench, we find that when selling straddles on the most liquid currency pairs, the gamma term is the largest contributor to performance. Zooming in further on that term, we find that it can be expressed as the sum of two components: one which we will call the volatility premium component which is roughly proportional to the volatility premium, i.e. to traded volatility minus realised volatility, and another which we will call the gamma covariance effect and which is proportional to the correlation between the option gamma and the squared returns of the underlying. We find that the term that scales the volatility premium in the volatility premium component exhibits little correlation with the realised volatility of the underlying or with the volatility premium itself, and that the gamma covariance term can contribute to the performance significantly, especially in times of market stress.

All in all, this shows that a simple vanilla instrument can be used to reliably capture the so-called volatility premium, especially within the framework of systematic strategies. The variations in gamma are averaged away over time, resulting in fairly stable exposure to the volatility premium. These results not only provide a better understanding of canonical systematic volatility strategies such as the sale of straddles, but can also be used to size directional or relative value trades that rely on vanilla options.

We will now present our mathematical results, and use them to analyse the performance of short straddle strategies on G10 currency pairs over the past 13 years.

2. Linking volatility premium and performance

2.1. Disentangling gamma and vega

Let P(σ, r, q, T) be the Black-Scholes price at time t of an option, with r the risk-free rate and q the underlying's dividend rate. If we assume for the time being that the implied volatility σ is fixed, then the performance of that delta hedged option over a small time window is:

$$\begin{aligned} P\&L &= d\left(e^{-rt}P\right) - \frac{\partial P}{\partial S} d\left(e^{-rt}S\right) \\ &= e^{-rt}\left[-rPdt + \frac{\partial P}{\partial t}dt + \frac{\partial P}{\partial S}dS + \frac{1}{2}\frac{\partial^2 P}{\partial S^2}d\left\langle S\right\rangle\right] \\ &\quad - e^{-rt}\frac{\partial P}{\partial S}\left[-(r-q)Sdt + dS\right] \\ &= e^{-rt}\left[-rPdt + \frac{\partial P}{\partial t}dt + \frac{1}{2}\frac{\partial^2 P}{\partial S^2}d\left\langle S\right\rangle + (r-q)S\frac{\partial P}{\partial S}dt\right], \end{aligned} \qquad (1)$$

where ⟨.⟩ denotes quadratic variations. By design, *P* satisfies the Black-Scholes equation:

$$-rPdt + \frac{\partial P}{\partial t}dt + \frac{1}{2}\frac{\partial^2 P}{\partial S^2}\sigma^2 S^2 dt + (r-q)S\frac{\partial P}{\partial S}dt = 0$$

Therefore (1) becomes

$$P\&L = e^{-rt}\left[\frac{1}{2}\frac{\partial^2 P}{\partial S^2}\left(d\left\langle S\right\rangle - \sigma^2 S^2 dt\right)\right]$$

If we now let σ float, three new terms enter the fray:

$$P\&L = e^{-rt}\left[\frac{1}{2}\frac{\partial^2 P}{\partial S^2}\left(d\left\langle S\right\rangle - \sigma^2 S^2 dt\right) + \frac{\partial P}{\partial \sigma}d\sigma + \frac{1}{2}\frac{\partial^2 P}{\partial \sigma^2}d\left\langle \sigma\right\rangle + \frac{\partial^2 P}{\partial \sigma \partial S}d\left\langle S,\sigma\right\rangle\right] \qquad (2)$$

(2) is a useful tool for market makers, whose main objective is to manage their greeks and risk. It can also be used to calculate P&L attribution over a short time interval.

However, as a tool to understand performance over a longer interval, such as the life of the option, it is lacking, primarily because of the interplay between the terms in gamma and vega. For instance, assume that an investor is short an option. His or her Black-Scholes vega and gamma is negative, which implies that an instantaneous rise in implied volatility will cause a drop in P&L, through the vega term. But that same rise in implied volatility also entails that the break-even of the option seller increases, i.e. the level at which he starts to lose money through the gamma term also increases.

Remember (e.g. Bergomi, 2016, p181) that under Black-Scholes, gamma and vega are linked:

$$\frac{\partial P}{\partial \sigma} = S^2\frac{\partial^2 P}{\partial S^2}\sigma(T-t) \qquad (3)$$

Focusing for now on the gamma and vega part of the equation, we set:

$$P\&L_{GV} := e^{-rt}\left[\frac{1}{2}\frac{\partial^2 P}{\partial S^2}\left(d\langle S\rangle - \sigma^2 S^2 dt\right) + \frac{\partial P}{\partial \sigma}d\sigma\right] \quad (4)$$

Using (3) this becomes:

$$P\&L_{GV} = e^{-rt}\left[\frac{1}{2}\frac{\partial^2 P}{\partial S^2}\left(d\langle S\rangle - \sigma^2 S^2 dt\right) + S^2\frac{\partial^2 P}{\partial S^2}\sigma(T-t)d\sigma\right]$$

Now note that, by Itô:

$$d\sigma^2 = 2\sigma\, d\sigma + d\langle\sigma\rangle.$$

Therefore:

$$P\&L_{GV} = e^{-rt}\frac{1}{2}S^2\frac{\partial^2 P}{\partial S^2}\left[\left(\frac{d\langle S\rangle}{S^2} - \sigma^2 dt\right) + (T-t)(d\sigma^2 - d\langle\sigma\rangle)\right]$$

Setting $\Gamma_\$ = S^2\,\partial^2 P/\,\partial S^2$ and $\sigma_0 = \sigma(t_0)$ as the implied volatility at trade date, we obtain:

$$\begin{aligned}
P\&L_{GV} &= e^{-rt}\frac{1}{2}\Gamma_\$\left[\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right) + (\sigma_0^2 - \sigma^2)dt + (T-t)\left(d\sigma^2 - d\langle\sigma\rangle\right)\right] \\
&= \frac{e^{-rt}}{2}\Gamma_\$\left[\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right) + (\sigma_0^2 - \sigma^2)dt + (T-t)d\sigma^2 - (T-t)d\langle\sigma\rangle\right] \\
&= \frac{e^{-rt}}{2}\Gamma_\$\left[\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right) + d\left((T-t)(\sigma^2 - \sigma_0^2)\right) - (T-t)d\langle\sigma\rangle\right] \\
&= \frac{e^{-rt}}{2}\Gamma_\$\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right) + \frac{e^{-rt}}{2}\Gamma_\$ d\left((T-t)(\sigma^2 - \sigma_0^2)\right) \\
&\quad - \frac{e^{-rt}}{2}\Gamma_\$(T-t)d\langle\sigma\rangle \qquad (5)
\end{aligned}$$

Let $\Gamma^* := e^{-rt}\Gamma$ be the discounted dollar gamma. Per Itô's formula, for any two functions U and V,

$$d(UV) = UdV + V\,dU + d\langle UV\rangle.$$

Applying this to the middle term in (5) yields

$$\begin{aligned}
P\&L_{GV} = \Bigg[&\frac{\Gamma^*}{2}\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right) + \frac{1}{2}d\left(\Gamma^*(T-t)(\sigma^2 - \sigma_0^2)\right) \\
&-\frac{(T-t)}{2}(\sigma^2 - \sigma_0^2)d\Gamma^* - \frac{(T-t)}{2}d\langle\sigma^2, \Gamma^*\rangle - \frac{\Gamma^*}{2}(T-t)d\langle\sigma\rangle\Bigg] \qquad (6)
\end{aligned}$$

Using (3) we can rewrite the inner part of the middle term as

$$
\begin{aligned}
\frac{1}{2}\left(\Gamma^*(T-t)(\sigma^2-\sigma_0^2)\right) &= \frac{1}{2}e^{-rt}S^2\frac{\partial^2 P}{\partial S^2}(T-t)(\sigma^2-\sigma_0^2) \\
&= \frac{1}{2}e^{-rt}S^2\frac{\partial^2 P}{\partial S^2}(T-t)\frac{\sigma}{\sigma}(\sigma^2-\sigma_0^2) \\
&= \frac{1}{2}e^{-rt}S^2\frac{\partial^2 P}{\partial S^2}(T-t)\frac{\sigma}{\sigma}(\sigma+\sigma_0)(\sigma-\sigma_0) \\
&= e^{-rt}\frac{\partial P}{\partial \sigma}\frac{\sigma+\sigma_0}{2\sigma}(\sigma-\sigma_0)
\end{aligned} \tag{7}
$$

Using this in (6) yield

$$
\begin{aligned}
P\&L_{GV} = \Bigg[&\frac{\Gamma^*}{2}\left(\frac{d\langle S\rangle}{S^2}-\sigma_0^2 dt\right) + d\left(e^{-rt}\frac{\sigma+\sigma_0}{2\sigma}\frac{\partial P}{\partial \sigma}(\sigma-\sigma_0)\right) \\
&-\frac{(T-t)}{2}(\sigma^2-\sigma_0^2)d\Gamma^* - \frac{(T-t)}{2}d\left\langle\sigma^2,\Gamma^*\right\rangle - \frac{\Gamma^*}{2}(T-t)d\langle\sigma\rangle\Bigg]
\end{aligned} \tag{8}
$$

Comparing (4) and (8), a few things stand out:

- The first term now features the initial implied volatility, rather than volatility at any point in time.
- The second term is the Itô derivative of a function that is worth zero when t is equal to t_0 and T. Therefore, the integral of that term over (t_0, T) is zero. This means that the total contribution of this term to performance over the life of the trade is null and that it only adds noise. In what follows, we will call it the vega term.
- The third term is proportional to the change in discounted dollar gamma, times the distance between live and traded implied volatility. As we shall see empirically, the total contribution from this term is often small. One reason might lie in the fact that in the Black-Scholes framework, Γ^* is a martingale (see Bergomi, 2016, p181, for example), causing that term to have a zero average. Asset prices do not follow Black-Scholes in real life, but it would nevertheless be plausible for this term to remain in the vicinity of its Black-Scholes average (i.e. 0). In what follows, we will call it the dGamma term.
- The remaining two terms are residual drift terms.

2.2. From gamma P&L to volatility premium

Let's now focus on the gamma component of (6), which we reproduce here for convenience:

$$
\begin{aligned}
P\&L_{GV} = \Bigg[&\overbrace{\frac{1}{2}\Gamma^*\left(\frac{d\langle S\rangle}{S^2}-\sigma_0^2 dt\right)}^{\text{Gamma term}} + d\left(e^{-rt}\frac{\sigma+\sigma_0}{2\sigma}\frac{\partial P}{\partial \sigma}(\sigma-\sigma_0)\right) \\
&-\frac{(T-t)}{2}(\sigma^2-\sigma_0^2)d\Gamma^* - \frac{(T-t)}{2}d\left\langle\sigma^2,\Gamma^*\right\rangle - \frac{\Gamma^*}{2}(T-t)d\langle\sigma\rangle\Bigg]
\end{aligned} \tag{9}
$$

For any t in (t0, T) we have:

$$\int_0^t \Gamma^* \left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 du\right) = \int_0^t \Gamma^* \frac{d\langle S\rangle}{S^2} - \sigma_0^2 \int_0^t \Gamma^* du \qquad (10)$$

We set $t_0 := 0$, denote $\overline{(.)}$ the empirical average of any function between t_0 and t

$$\bar{f} := \frac{1}{t-t_0} \int_{t_0}^t f(u)du$$

and let $d\langle S\rangle/du$ *be* the Radon–Nikodym derivative of $d\langle S\rangle$ with respect to du. In particular, we can rewrite the first part of (10) as:

$$\int_0^t \Gamma^* \frac{d\langle S\rangle}{S^2} = t\left(\frac{1}{t}\int_0^t \Gamma^* \frac{d\langle S\rangle}{S^2 du} du\right).$$

Note now that for any functions f,g,

$$\frac{1}{t}\int_0^t f(u)g(u)du = \bar{f}\bar{g} + \frac{1}{t}\int_0^t (f(u)-\bar{f})(g(u)-\bar{g})du.$$

Therefore:

$$\begin{aligned}
\int_0^t \Gamma^* \frac{d\langle S\rangle}{S^2} &= t\left(\frac{1}{t}\int_0^t \Gamma^* \frac{d\langle S\rangle}{S^2 du} du\right) \\
&= t\left(\overline{\Gamma^*}\frac{1}{t}\int_0^t \frac{d\langle S\rangle}{S^2 du}du + \frac{1}{t}\int_0^t \left(\Gamma^* - \overline{\Gamma^*}\right)\left(\frac{d\langle S\rangle}{S^2 du} - \overline{\frac{d\langle S\rangle}{S^2 du}}\right)du\right) \\
&= t\left(\overline{\Gamma^*}\frac{1}{t}\int_0^t \frac{d\langle S\rangle}{S^2}\right. \\
&\quad \left. + \rho\sqrt{\frac{1}{t}\int_0^t \left(\Gamma^* - \overline{\Gamma^*}\right)^2 du}\sqrt{\frac{1}{t}\int_0^t \left(\frac{d\langle S\rangle}{S^2 du} - \overline{\frac{d\langle S\rangle}{S^2 du}}\right)^2 du}\right)
\end{aligned}$$

where

$$\rho = \frac{\frac{1}{t}\int_0^t \left(\Gamma^* - \overline{\Gamma^*}\right)\left(\frac{d\langle S\rangle}{S^2 du} - \overline{\frac{d\langle S\rangle}{S^2 du}}\right)du}{\sqrt{\frac{1}{t}\int_0^t \left(\Gamma^* - \overline{\Gamma^*}\right)^2 du}\sqrt{\frac{1}{t}\int_0^t \left(\frac{d\langle S\rangle}{S^2 du} - \overline{\frac{d\langle S\rangle}{S^2 du}}\right)^2 du}}. \qquad (11)$$

Letting

$$\sigma_r := \sqrt{\frac{1}{t}\int_0^t \frac{d\langle S\rangle}{S^2}}$$

be the realised volatility over (0,t), (10) becomes:

$$\int_0^t \Gamma^* \left(\frac{d\langle S \rangle}{S^2} - \sigma_0^2 du \right) = t\overline{\Gamma^*} \left(\sigma_r^2 - \sigma_0^2 \right) + t\rho \mathrm{Stdev}(\Gamma^*) \mathrm{Stdev} \left(\frac{d\langle S \rangle}{S^2 du} \right)$$

where $\mathrm{Stdev}(.)$ is the sample standard deviation, i.e. for any function *f*:

$$\mathrm{Stdev}(f) := \sqrt{\frac{1}{t} \int_0^t (f(u) - \bar{f})^2 du}.$$

Using $a^2 - b^2 = (a - b)(a + b)$ and reintroducing the 1/2 factor from (7), we have:

$$\int_0^t \frac{1}{2}\Gamma^* \left(\frac{d\langle S \rangle}{S^2} - \sigma_0^2 du \right) = \left(t\overline{\Gamma^*} \frac{\sigma_r + \sigma_0}{2} \right) (\sigma_r - \sigma_0) + \frac{t}{2}\rho \ \mathrm{Stdev}(\Gamma^*) \ \mathrm{Stdev} \left(\frac{d\langle S \rangle}{S^2 du} \right) \quad (12)$$

A few takeaways from that equation:

- **Takeaways from the first term**, which we will call the *volatility premium component*. This term is equal to the volatility premium, $\sigma_r - \sigma_0$, times a scaling factor, which we will call the *volatility premium scaling factor* and which is equal to $T\Gamma(\sigma_r + \sigma_0)$. Recall from Black-Scholes greeks that Γ scales like the inverse of implied volatility. Therefore we would expect $\Gamma(\sigma_r + \sigma_0)/2$ to be relatively insensitive to the overall level of implied volatility over the interval. In summary, the first component in the sum above can be thought of as being equal to the traditional volatility premium, times a measure of the average gamma on the path that has little sensitivity to volatility.
- As mentioned previously, in the Black-Scholes framework Γ^* is a martingale, and therefore the expected value of Γ^* is equal to ${\Gamma^*}_{t=0}$. In the real world, one would therefore expect the volatility premium scaling factor $\mathrm{T}\overline{\Gamma^*}(\sigma_r + \sigma_0)/2$ to average around $T\Gamma^*_{t=0}(\sigma_r + \sigma_0)/2$. From (3), this looks a lot like $\partial P/\partial\sigma(t = 0)$, with the twist that traded volatility is replaced by the average between traded and realised volatility. In other words, the average volatility premium scaling factor is likely close to vega at inception.
- In a way, that volatility premium component can be thought of as the part of the option performance that resembles that of a strike-free structure like a volatility swap.
- **Takeaways from the second term**. Since $d\langle S \rangle / S^2 du$ can be thought of as a continuous-time way to write squared returns, the second component of (12) is a function of:
  - the standard deviation of squared returns;
  - the standard deviation of Γ^* on the path;
  - and the correlation between Γ^* and squared returns.
- We will call that second component the *gamma covariance effect*. By contrast with the volatility premium component defined above, the gamma covariance effect corresponds to the fraction of the gamma term (see (2)) which does not primarily depend on realised volatility. As we shall see, its contribution can be significant.

To finish this section, we present the discrete time equivalent of the notations involved in (12). Sampling the integral at $t_j, i = 1 \cdots N$, with returns $r_j = S_{t_j}/S_{t_{j-1}}$, setting $\Delta_i = t_{i+1} - t_i$, defining $\bar{a} = (1/T) \sum_{i=1}^{N} a_i \Delta_i$ for any time series a, and discretising the finite variations of S as follows:

$$\langle S \rangle_{t_i} = \sum_{j=2}^{i} S_{t_{j-1}}^2 r_j^2$$

we obtain:

$$\left(\frac{d \langle S \rangle}{S^2 dt} \right)_{t_i} = \frac{r_i^2}{\Delta_i}$$

$$v_r = \sqrt{\frac{\sum_{i=2}^{N} r_i^2}{T}}$$

$$\overline{\Gamma^*} = \frac{1}{T} \sum_{i=1}^{N} \Gamma^*(t_i) \Delta_i$$

$$\mathrm{Stdev}(\Gamma^*) = \sqrt{\frac{1}{T} \sum_{i=2}^{N} (\Gamma^*(t_i) - \overline{\Gamma^*})^2 \Delta_i}$$

$$\mathrm{Stdev}\left(\frac{d \langle S \rangle}{S^2 dt} \right) = \sqrt{\frac{1}{T} \sum_{i=1}^{N} \left(\frac{r_i}{\Delta_i}^2 - \frac{\overline{r^2}}{\Delta} \right)^2 \Delta_i}$$

$$\rho = \frac{\frac{1}{T} \sum_{i=1}^{N} (\Gamma^*(t_i) - \overline{\Gamma^*}) \left(\frac{r_i}{\Delta_i}^2 - \frac{\overline{r^2}}{\Delta} \right) \Delta_i}{\sqrt{\frac{1}{T} \sum_{i=1}^{N} \left(\frac{r_i}{\Delta_i}^2 - \frac{\overline{r^2}}{\Delta} \right)^2 \Delta_i} \sqrt{\frac{1}{T} \sum_{i=2}^{N} (\Gamma^*(t_i) - \overline{\Gamma^*})^2 \Delta_i}}$$

3. An example – Selling straddles in currencies

In this section, we use the results from the above section to analyse the performance of a well-known option strategy: selling a straddle and hedging it at regular intervals.

Our backtest relies on Bloomberg for implied volatility and FX spot data. It rebalances the delta at the London close every business day and calculates the delta based on the spot level observed at the 10am NY fixing and on the volatility level observed on the prior day's close. This lag is introduced to make the backtest as realistic as possible. We also stagger the backtest start dates. For monthly options, for example, this means that one quarter of the full nominal will be sold on the backtest's start date, another quarter one week later, and so on and so forth. This tweak reduces the noise induced by the choice of a specific start date and should allow the sampled volatility premium scaling factor (see section 3.3.1) to converge faster to its mean. We focus on some of the main G7 currency pairs, namely EURUSD, USDJPY, GBPUSD, EURGBP, USDCAD, AUDUSD, USDNOK, USDSEK, USDCHF and EURCHF, and on one week, one month, six months and 1y option tenors.

We are now going to merge (2) and (9). Let us first tidy the four quadratic variation terms included in these equations. Letting $\mathcal{V} \coloneqq \partial P/\,\partial$, and noting that from (3)

$$(T-t)\Gamma^* d\sigma + \sigma(T-t)d\Gamma^* + (T-t)d\left\langle \Gamma^*, \sigma \right\rangle = e^{-rt} d\mathcal{V} \tag{13}$$

we can rewrite the four quadratic variation blocks in (2) and (9) as

$$\begin{aligned} -\frac{(T-t)}{2} d\left\langle \sigma^2, \Gamma^* \right\rangle - \frac{(T-t)}{2}\Gamma^* d\left\langle \sigma \right\rangle + e^{-rt}\left(\frac{1}{2}\frac{\partial^2 P}{\partial \sigma^2} d\left\langle \sigma \right\rangle + \frac{\partial^2 P}{\partial \sigma \partial S} d\left\langle S, \sigma \right\rangle\right) \\ = \frac{e^{-rt}}{2}\left(\frac{\mathcal{V}}{\sigma} - \frac{\partial \mathcal{V}}{\partial \sigma}\right) d\left\langle \sigma \right\rangle \end{aligned} \tag{14}$$

From (2), (9), (12), (14) and the terminology that we introduced in section 2.1, the performance of an option portfolio over (0, t) can be broken down as follows:

$$\begin{aligned} P\&L = \Bigg[& \overbrace{\left(t\overline{\Gamma^*}\frac{\sigma_r + \sigma_0}{2}\right)(\sigma_r - \sigma_0)}^{\text{Volatility premium component}} + \overbrace{\frac{t}{2}\rho \text{ Stdev}(\Gamma^*) \text{ Stdev}\left(\frac{d\left\langle S \right\rangle}{S^2 du}\right)}^{\text{Gamma covariance effect}} \\ & \underbrace{+ e^{-rt}\frac{\sigma + \sigma_0}{2\sigma}\frac{\partial P}{\partial \sigma}(t)(\sigma - \sigma_0)}_{\text{Vega term}} - \underbrace{\int_0^t \frac{(T-u)}{2}(\sigma^2 - \sigma_0^2) d\Gamma^*}_{\text{dGamma term}} \\ & \underbrace{-\int_0^t \frac{e^{-ru}}{2}\left(\frac{\mathcal{V}}{\sigma} - \frac{\partial \mathcal{V}}{\partial \sigma}\right) d\left\langle \sigma \right\rangle}_{\text{Residual drift term}} \Bigg] \end{aligned} \tag{15}$$

– a *gamma term*, which is a function of realised volatility and traded volatility;

– a *vega term*, which adds up to zero over the life of the option;

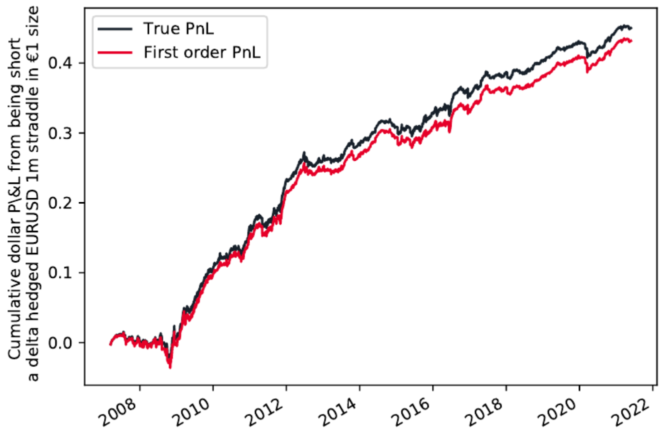
– a term that we call the *dGamma term* that's proportional to the variation in Gamma and to the difference between traded volatility and implied volatility along the path;

– and finally, some residual drift terms.

3.1 The first order expansion explains performance well

As figure 1 illustrates, this first order breakdown (or equation (2) since they are equivalent) does a decent job at explaining the strategy's performance. The difference that is left comes from the delta hedging frequency (daily vs continuous) and from the discretisation of the performance calculation.

Figure 1. First order terms explain most of the performance



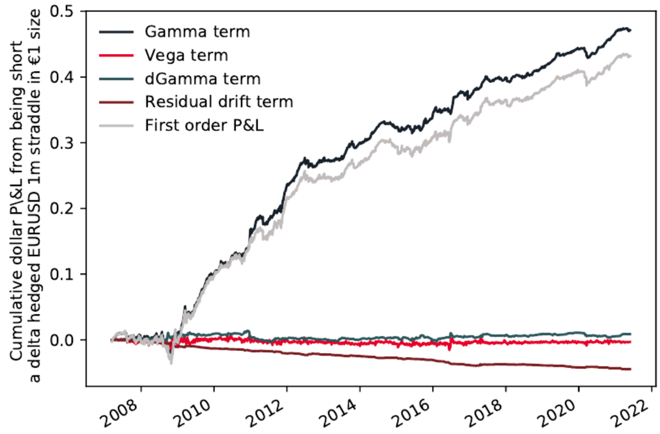
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

With our simulated short straddle strategies, that difference is positive, i.e. the real performance is higher than the first order performance. That makes sense intuitively, once we observe that for a short straddle position, gamma troughs around the money, in the vicinity of which the underlying will stay on average. On each discrete time interval, gamma is therefore likely to be higher than at the starting point of the interval. This means that the first order expansion, whose coefficients are set at the starting point of each interval, will likely overestimate the strategy's negative convexity and therefore underestimate its performance.

3.2 Gamma is the main performance driver

Now that we know that the performance of a short straddle strategy is well approximated by its first order expansion, we would like to know which one of these terms dominates, especially now that the performance equation has been rewritten across seemingly unrelated components.
In figure 2, which focuses on one-month EURUSD straddles, gamma is clearly the main driver. This is also the case on average for other currency pairs and tenors, as we shall see in section 3.4 once we have introduced the tools to measure that contribution.

Figure 2. Contribution of the four blocks – EURUSD 1m



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

We will now try to gain a better understanding of this gamma term and see how it relates to the volatility premium.

3.3 Zooming in on the gamma component

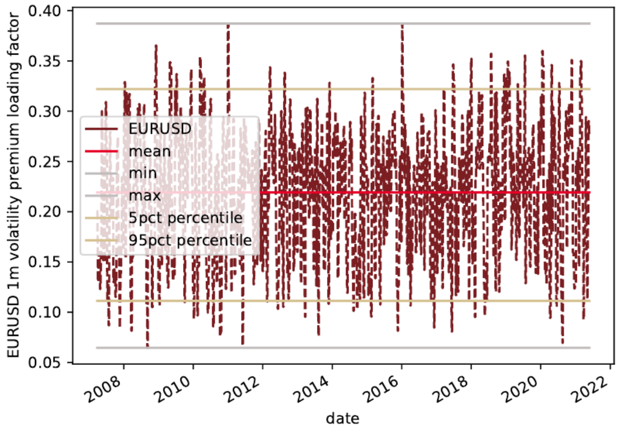
3.3.1 First, the volatility premium

Equation (12) shows that the gamma component can be broken up as the sum of two terms. Per section 2.2 we call the first one the *volatility premium component* and the second the *gamma covariance effect*:

$$\overbrace{\int_0^T \frac{\Gamma}{2}\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right)}^{\text{Gamma term}} = \underbrace{\left(T\overline{\Gamma}\frac{(\sigma_r+\sigma_0)}{2}\right)(\sigma_r-\sigma_0)}_{\text{Volatility premium component}} + \underbrace{\frac{T}{2}\rho\ \mathrm{Stdev}(\Gamma)\ \mathrm{Stdev}\left(\frac{d\langle S\rangle}{S^2 dt}\right)}_{\text{Gamma covariance effect}}$$

The volatility premium component is equal to the volatility premium times a quantity which we call the *volatility premium scaling factor* (cf section 2.2). It is equal to the average gamma along the path, times the average of traded and realised volatility. Figure 3 shows what it looks like for 1m EURUSD straddles.

Figure 3. The volatility premium scaling factor oscillates but remains mostly range bound



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

One of the main features of the volatility premium scaling factor is that it oscillates. This makes sense intuitively, as the average gamma through the life of the option is a function of how far the spot strays from the strike. Therefore, the variations in the terminal value of the spot around the strike translate into oscillations of the average gamma. The chart also shows that the volatility scaling factor remains mostly range bound.

As we expected in one of the bullet points of section 2.2, it is also not very dependent on the volatility regime, thanks to the mathematical relationship between gamma and implied volatility. In particular, and as shown in table 1, the average correlation between the volatility premium scaling factor and realised volatility is low on average.

Table 1. Average correlation between the vol premium scaling factor and realised volatility

	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg.
1 week	0.00	0.62	0.01	0.10	0.02	0.00	0.14	0.02	0.05	0.07	0.10
1 month	-0.02	0.43	-0.12	0.00	-0.06	-0.04	0.01	-0.09	0.05	0.01	0.02
6 months	-0.15	0.22	-0.18	0.06	-0.16	-0.22	0.05	-0.25	-0.09	-0.06	-0.08
1 year	-0.10	0.17	-0.17	0.12	-0.21	-0.31	-0.07	-0.36	-0.17	-0.17	-0.13
Avg.	-0.07	0.36	-0.11	0.07	-0.10	-0.14	0.03	-0.17	-0.04	-0.04	-0.02

Source: SG Cross Asset Research/Cross Asset Quant

This lack of market regime dependency, combined with the fast pace of oscillations, means that the volatility premium scaling factor should be relatively constant, when sampled across a reasonably long interval of time.

Critically, it is also decorrelated from the volatility premium. Table 2 shows that the average correlation between the volatility premium scaling factor and ex-post volatility premium is small. This decorrelation, together with the relative stationarity of the volatility premium scaling factor as described above, means that on the first order the volatility premium component is equal to the volatility premium times a constant, itself equal to the empirical average of the volatility premium scaling factor.

Table 2. Average correlation between the vol premium scaling factor and the vol premium

	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg.
1 week	-0.08	-0.75	-0.01	0.03	-0.02	-0.06	-0.10	-0.09	-0.11	-0.11	-0.13
1 month	0.05	-0.57	0.17	0.22	0.11	0.09	0.03	0.01	-0.07	-0.01	0.00
6 months	0.22	-0.22	0.29	0.21	0.28	0.16	-0.08	0.17	-0.06	0.16	0.11
1 year	0.21	-0.10	0.42	0.24	0.30	0.05	0.03	0.22	0.01	0.24	0.16
Avg.	0.10	-0.41	0.22	0.18	0.17	0.06	-0.03	0.08	-0.06	0.07	0.04

Source: SG Cross Asset Research/Cross Asset Quant

3.3.2 Average volatility scaling factor

For $100 invested at every option roll, table 3 shows what the average volatility premium scaling factor looks like. In particular, this number tells us what size one needs to trade for a given profit objective and a given amount of volatility premium. Among other benefits, normalising by this factor makes a performance comparison across option tenors possible, as we shall see in what follows.

Table 3. Average volatility scaling factor per year, for $100 straddle notional invested

Tenor	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK
1 week	5.39	5.72	5.37	5.35	5.38	5.30	5.40	5.31	5.38	5.30
1 month	2.72	2.80	2.61	2.62	2.69	2.68	2.64	2.78	2.71	2.66
6 months	1.18	1.28	1.11	1.06	1.11	1.19	1.21	1.17	1.15	1.14
1 year	0.81	0.94	0.80	0.75	0.84	0.86	0.94	0.86	0.85	0.79

Source: SG Cross Asset Research/Cross Asset Quant

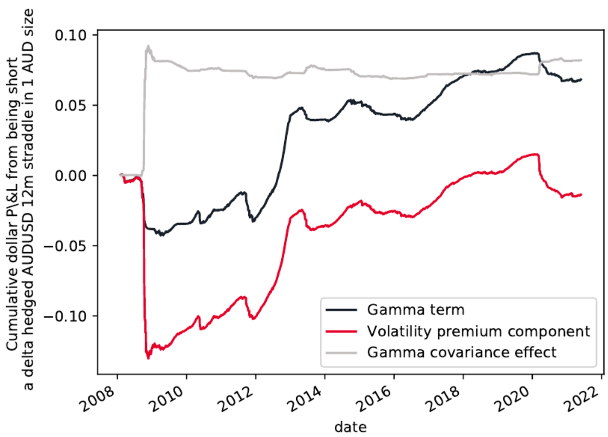
3.3.3 Gamma covariance effect

As mentioned in section 3.3.1, the gamma covariance effect is equal to the pathwise covariance between gamma and squared returns:

$$\overbrace{\int_0^T \frac{\Gamma^*}{2}\left(\frac{d\langle S\rangle}{S^2} - \sigma_0^2 dt\right)}^{\text{Gamma term}} = \underbrace{\left(T\overline{\Gamma^*}\frac{(\sigma_r+\sigma_0)}{2}\right)(\sigma_r - \sigma_0)}_{\text{Volatility premium component}} + \underbrace{\frac{T}{2}\rho\ \mathrm{Stdev}(\Gamma^*)\ \mathrm{Stdev}\left(\frac{d\langle S\rangle}{S^2 dt}\right)}_{\text{Gamma covariance effect}}$$

Figure 4 illustrates that component for 12m straddles on AUDUSD. It shows that it contributes very positively in 2008 and to a lesser extent in March 2020, allowing the gamma P&L of the strategy to largely outperform its volatility premium component. In particular, the gamma covariance effect explains why selling long-dated options on AUDUSD would have been profitable over that period, even though the average volatility premium has been close to zero over that time window (per table 6 in the Appendix).

Figure 4. The gamma term broken down for AUDUSD 12m



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Taking a step back and broadening the analysis to other currencies and tenors, the gamma covariance effect isn't always favourable to the option seller. Table 4 shows the average contribution of that component to performance, normalised by the average volatility scaling factor. For 12m AUDUSD straddles, the impact is 0.90 volatility points, or in other words, the part of the performance attributable to gamma is 0.90 volatility points higher than the average volatility premium over that time window would indicate. For 1m AUDUSD straddles, however, that impact is negative at -0.59. Looking across currencies, this is a general pattern: the gamma covariance effect is positive for long-dated options and negative for short-dated ones.

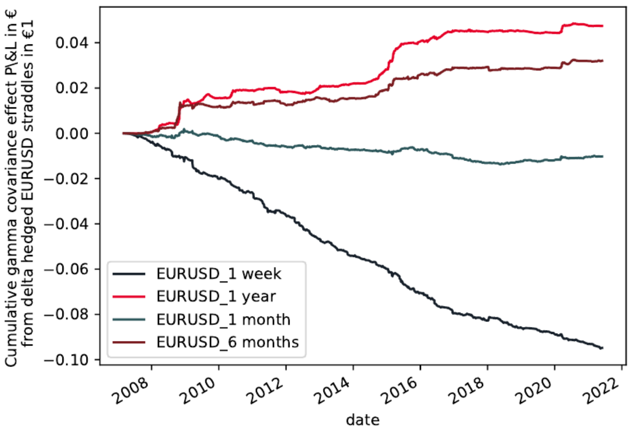
Table 4. Average yearly return from second gamma component per unit of average volatility premium scaling factor.

Currency pairs	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg
1 week	-0.59	-3.08	-0.45	-0.68	-0.52	-0.59	-1.06	-0.54	-0.73	-0.70	-0.89
1 month	0.13	-4.03	-0.09	-0.07	-0.05	-0.04	-0.19	-0.01	0.12	-0.12	-0.44
6 months	0.65	-0.75	0.09	0.23	0.19	0.31	0.49	0.24	0.66	0.24	0.24
1 year	0.90	-0.00	0.17	0.33	0.30	0.35	0.57	0.38	0.79	0.42	0.42
Average	0.27	-1.96	-0.07	-0.05	-0.02	0.01	-0.05	0.02	0.21	-0.04	-0.17

Source: SG Cross Asset Research/Cross Asset Quant

Figure 5 illustrates this phenomenon for EURUSD, normalising again by the average volatility scaling factor. We see in particular that this differentiating pattern is relatively stable over time and not caused by a few isolated events. The gamma covariance effect seems to take the form of a drift, negative for those selling short-dated options and positive for those selling long-dated ones.

Figure 5. The gamma covariance effect for various tenors, EURUSD



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

That is in part due to a similar pattern for ρ, the correlation between gamma and squared returns (see (9)). And as table 5 shows, ρ tends to grow with the time to expiry and not depend much on the currency pair.

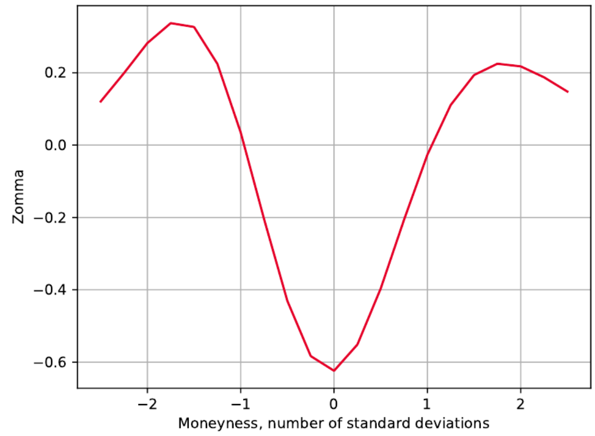
Table 5. Average path-wise correlation between Γ and squared returns

Currency pairs	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg.
1 week	-0.24	-0.18	-0.21	-0.31	-0.26	-0.24	-0.28	-0.22	-0.23	-0.24	-0.24
1 month	-0.04	-0.01	-0.03	-0.04	-0.03	-0.05	-0.05	-0.03	-0.03	-0.05	-0.04
6 months	0.03	0.08	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.02	0.03
1 year	0.04	0.08	0.04	0.05	0.04	0.04	0.02	0.05	0.04	0.04	0.04
Avg.	-0.06	-0.01	-0.04	-0.07	-0.06	-0.06	-0.07	-0.04	-0.05	-0.06	-0.05

Source: SG Cross Asset Research/Cross Asset Quant

This behaviour might be partly explained by the formulaic relationship between gamma and implied volatility. Gamma's derivative with respect to the underlying is called *speed*, and its derivative with respect to implied volatility is called *zomma*. Around the money the speed is zero, as gamma reaches a maximum there when considered a function of spot. By contrast, zomma is negative there, which is consistent with gamma scaling like the inverse of implied volatility, as we alluded to in previous sections. Away from the money, however, zomma becomes positive, as figure 6 shows.

Figure 6. Zomma is negative near the money but positive in the tails



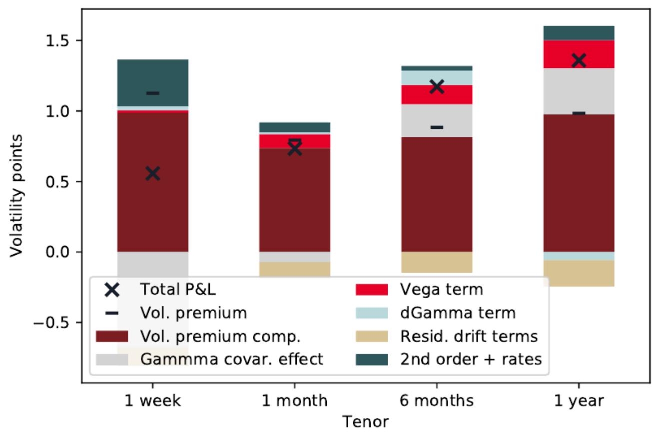
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Therefore one would expect the average zomma to be higher for underlyings with fatter tails, i.e. with higher vol of vol, and vice versa. This picture fits what we observe for short-dated vs long-dated returns, with the former being typically fatter tailed than the latter.

3.4 Attribution summary

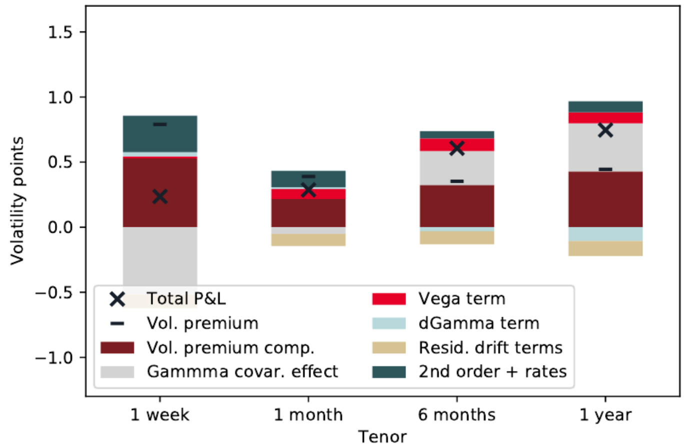
Putting these blocks together, we obtain a comprehensive picture of performance for short straddle strategies. Figure 7 shows this in the case of EURUSD and figure 8 shows the average across currency pairs. We scaled every one of these terms by the average volatility premium scaling factor, so that all quantities are expressed in volatility points.

Figure 7. Contribution of each P&L driver to total performance, in the case of EURUSD



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 8. Contribution of each P&L driver to total performance, average across currency pairs excluding CHF



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

We can draw a number of conclusions from these charts:

The first one is that the volatility premium component of the performance, in brown, is very close to the ex-post volatility premium (dash marker). This confirms our heuristic from section 3.3, namely that the lack of correlation between the ex post volatility premium and the volatility premium scaling factor on the one hand, and the high frequency of the latter on the other, made the volatility premium component behave as if the volatility premium scaling factor were roughly constant.

The second is that the gamma term is the largest contributor. On this chart, it is equal to the sum of the brown and grey bars, respectively, the volatility premium component and the gamma covariance effect. In particular, the gamma covariance effect is the second largest contributor. As seen in table 4, its contribution is negative for short-dated maturities and positive for long-dated ones.

Third, the vega term is small but not zero. As pointed out earlier, it adds up to zero when we hold the option to maturity, and that condition is not exactly satisfied in our simulation for two reasons. The first one is that the simulation's end date does not happen to match the last option's expiry date. The second is that, for technical reasons, some of the options are closed out a few days before expiry, which generates some P&L from this component.

Fourth, the dGamma term is relatively small.

Fifth, the residual drift terms are small too. Combined with the previous two observations, this shows that the path taken by implied volatility only has a minor impact on performance.

4. Conclusion

In this paper, we have proposed a novel representation for the P&L of a delta-hedged vanilla option and have used it to analyse the performance of the systematic sale of straddles. In particular, we have shown that the divergence between the performance of such a strategy and the ex post volatility premium is due to a covariance component. In our sample, from the perspective of the option seller, that effect is positive for long-dated maturities and strongly negative for short-dated ones. This explains in particular why it is difficult to capture the large volatility premium embedded in weekly options through straddles. We have also shown that, provided that the option is held to maturity, changes in implied volatility along the path do not impact the bottom-line P&L significantly. Finally, we have shown that the sensitivity of the performance to the volatility premium is equal to the path-wise average of gamma scaled by the option tenor and by the average of realised and traded volatility. As a direct application, this can be used as a tool to size positions, especially in the context of relative value strategies.

Topics for future research include further analysis of the gamma covariance effect. Table 5 gives us a hint that the correlation term does not depend much on the underlying and is mostly a function of the option tenor. It would be interesting to find the theoretical underpinnings of that empirical observation.

A. Appendix

A.1 Average volatility premium

Table 6. Average volatility premium

Currency pairs	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg.
1 week	0.69	0.89	1.03	1.13	0.93	0.93	0.47	1.52	0.69	0.87	0.91
1 month	0.01	0.43	0.66	0.79	0.5	0.48	0.1	0.89	0.14	0.37	0.44
6 months	-0.13	0.08	0.75	0.88	0.59	0.55	0.04	0.72	-0.16	0.31	0.36
1 year	0.05	-0.12	0.84	0.98	0.63	0.87	0.14	0.93	-0.2	0.35	0.45
Avg.	0.15	0.32	0.82	0.95	0.66	0.71	0.19	1.01	0.12	0.48	0.54

Source: SG Cross Asset Research/Cross Asset Quant

A.2 Standard deviation of ρ, the pathwise correlation between Γ^* and squared returns

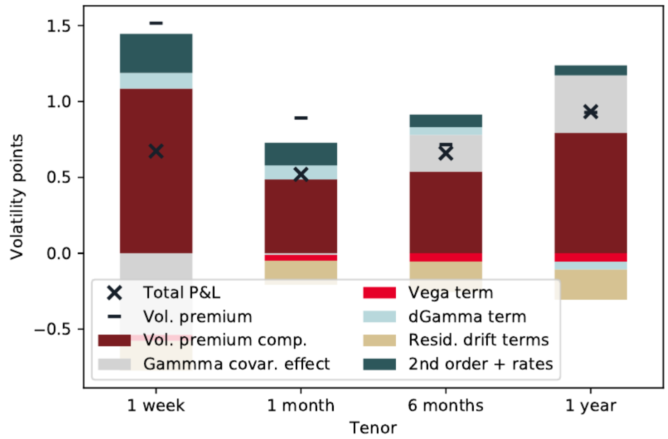
Table 7. Standard deviation of ρ, the pathwise correlation between Γ^* and squared returns

Currency pairs	AUDUSD	EURCHF	EURGBP	EURUSD	GBPUSD	USDCAD	USDCHF	USDJPY	USDNOK	USDSEK	Avg.
1 week	0.5	0.53	0.51	0.51	0.51	0.52	0.52	0.54	0.53	0.51	0.52
1 month	0.22	0.25	0.23	0.21	0.22	0.22	0.23	0.24	0.23	0.21	0.23
6 months	0.12	0.14	0.12	0.09	0.11	0.11	0.11	0.10	0.12	0.11	0.11
1 year	0.12	0.13	0.11	0.10	0.11	0.11	0.09	0.09	0.11	0.11	0.11
Avg.	0.24	0.26	0.24	0.23	0.24	0.24	0.24	0.24	0.25	0.24	0.24

Source: SG Cross Asset Research/Cross Asset Quant

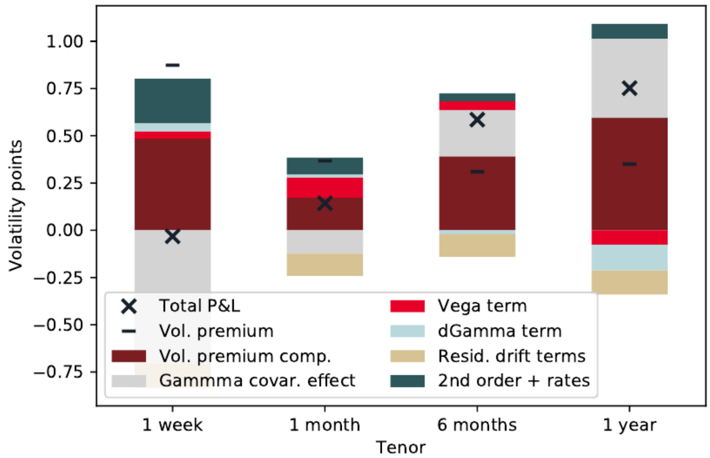
A.3 Attribution summary for all currency pairs

Figure 9. Contribution of each P&L driver to total performance, USDJPY



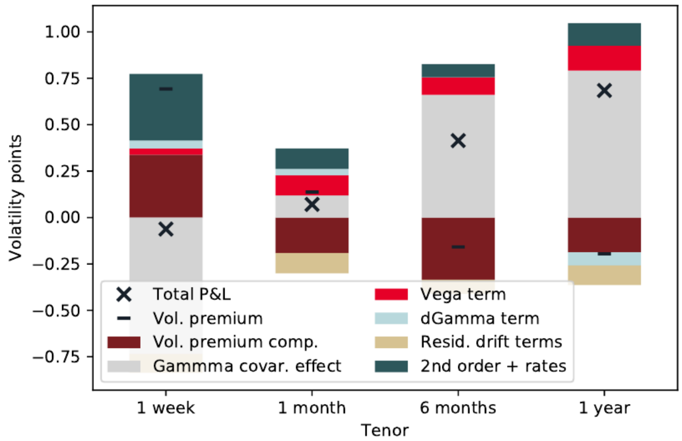
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 10. Contribution of each P&L driver to total performance, USDSEK



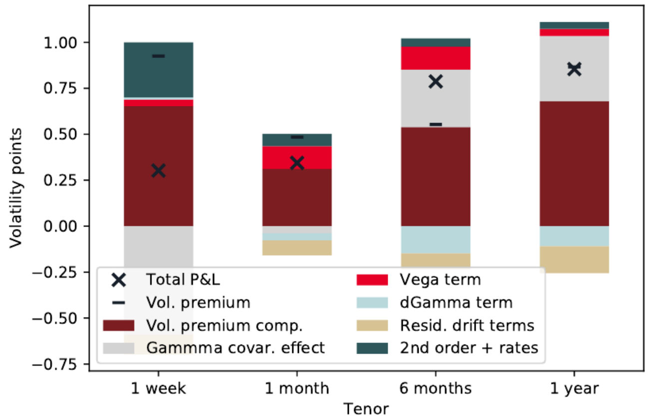
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 11. Contribution of each P&L driver to total performance, USDNOK



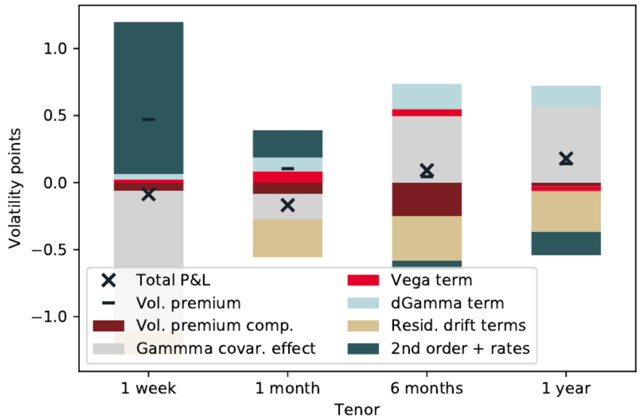
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 12. Contribution of each P&L driver to total performance, USDCAD



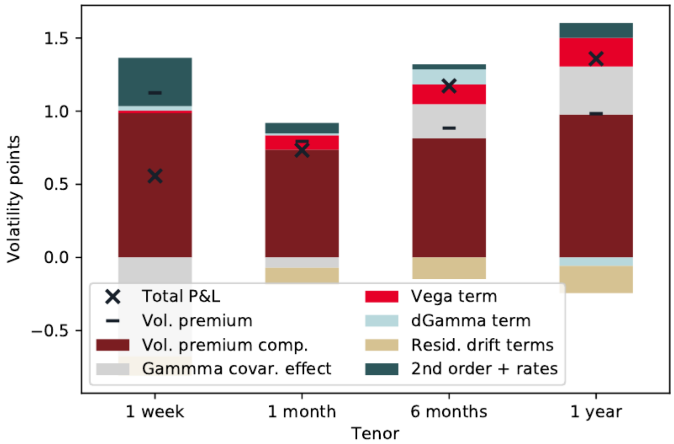
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 13. Contribution of each P&L driver to total performance, USDCHF



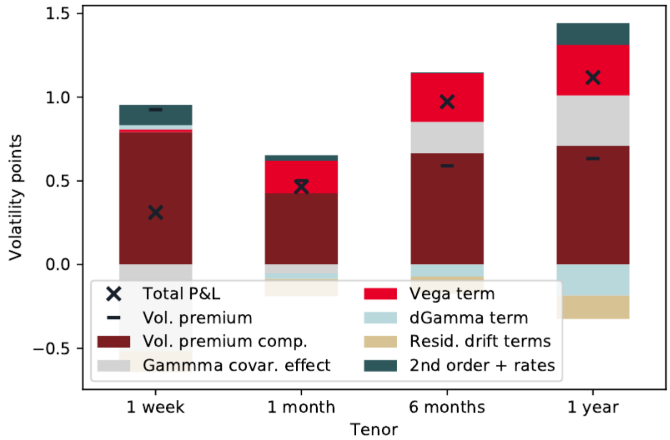
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 14. Contribution of each P&L driver to total performance, EURUSD



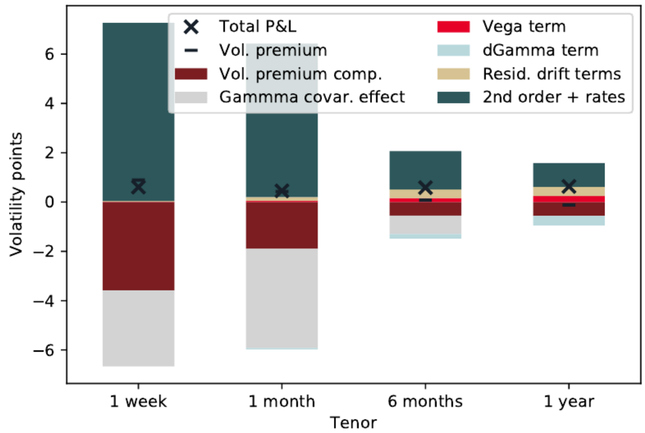
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 15. Contribution of each P&L driver to total performance, GBPUSD



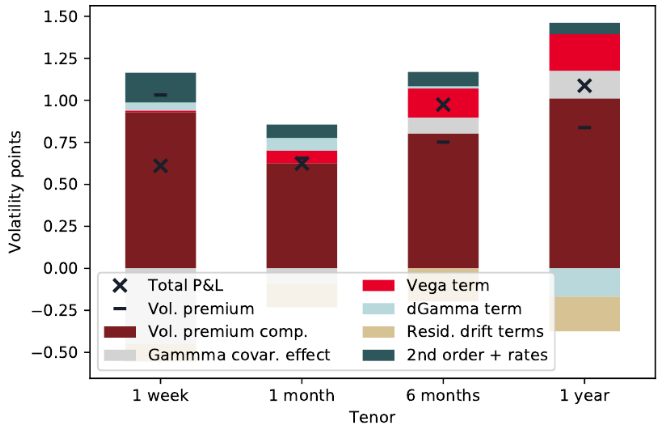
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 16. Contribution of each P&L driver to total performance, EURCHF



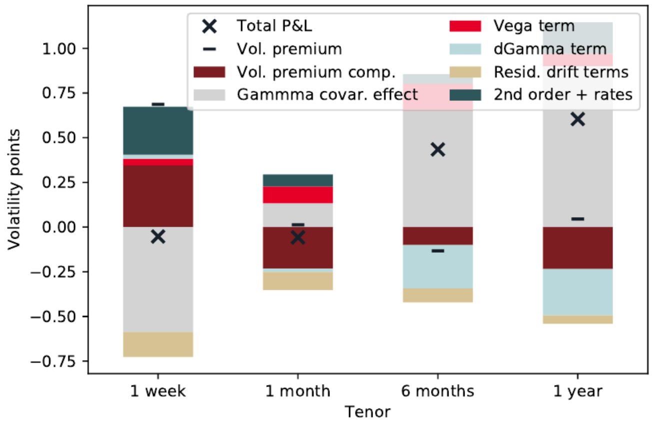
Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 17. Contribution of each P&L driver to total performance, EURGBP



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

Figure 18. Contribution of each P&L driver to total performance, AUDUSD



Source: SG Cross Asset Research/Cross Asset Quant, Bloomberg

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