J.P.Morgan

Global Quantitative & Derivatives Strategy
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Big Data and AI Strategies

Relative Value Trading on FX Volatility Surface

- We use the principal components of a transformation of the volatility surfaces of G10 FX pairs as predictor variables for a portfolio of option structures.
- We use a support vector machine (**SVM**) to model the PnLs of delta hedged options on the FX pairs using the values of the components.
- We show the model's expected PnLs for each of the option structures using a 1M holding period.

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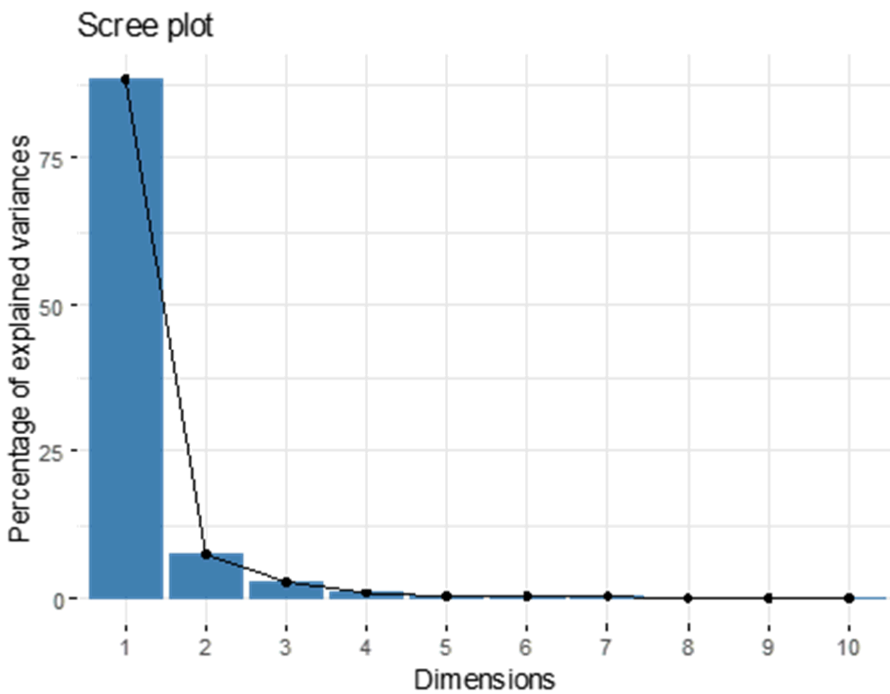
Figure 1: Variances of Principal Components of EUR/USD Vol Surface



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Introduction

We consider the principal components of a transformation of movements in the volatility surface of **G10 FX** pairs against **USD**. We find that for some pairs nearly all the variation of the surface dynamics can be explained by the first few components. We illustrate the concept by expressing the economic intuition behind each of the first **five** components for **EUR/USD**. We find that for this particular surface, the components can roughly be identified with the following five intuitive notions:

- **Parallel Shift**
- **Skew**
- **Term Structure Slope**
- **Surface Skew Twist**
- **Convexity**

We build a relative value trading strategy on the volatility surface by using a time series of the principal components as a signals and a Support Vector Machine as a model.

When considering our example of the principal components of **EUR/USD**, note that the qualitative descriptions of the components will not necessarily be in the same order for all currencies pairs. Additionally, we find that it is difficult to assign any meaning to the components after the first **five**. Furthermore, we note that even though the first component has a much larger variation than the others, this does not imply that it has more predictive power. Therefore, rather than using a threshold of variance to decide which components to use, we use a threshold of economic meaning. That is, we include the components that seem to have some real meaning or relevance that we find approximately includes the first **five**.

Principal Components

For each FX pair we consider the volatility levels at 15 pairs of delta and tenor levels. We use the **3, 6, and 12 Month** tenors and the following put/call delta values: **10 Delta Put, 25 Delta Put, 50 Delta Call, 25 Delta Call, and 10 Delta Call.** Therefore, for each day, we have a vector of dimension **15** of FX volatility levels, which represents our volatility surface.

Next we transform this vector in the following way: for each structure, we consider a rolling z-score by using its current volatility level and the mean and standard deviation of its volatility levels over the past **three** months.

After taking z-scores as described above, for each day we have a vector of dimension **15** where each component represents the recent movement of the volatility level of its corresponding structure. We compute the principal components of the collection of vectors going back to **~2011.** For example, for **EUR-USD** we have the following

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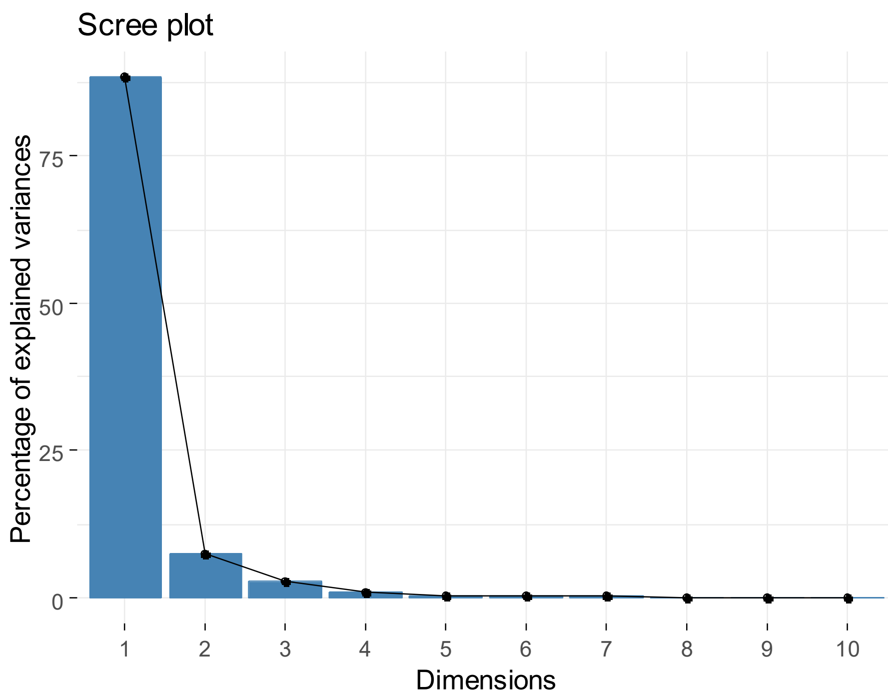
variation plot that tells us the size of the variation each component is responsible for. However, this plot does not give us any idea about what the actual components look like (e.g., parallel shift, smile, etc.). That information is illustrated in the subsequent figures. We also note that the example case study of the principal components is for **EUR/USD** only and that the properties of the **1st, 2nd** component, etc. are not necessarily the same for all volatility surfaces, although they are likely to be similar.



Source: J.P. Morgan

The next figure describes the **'shape' of the 1st principal component** (**PC1**). The components are scaled to have **length 1** (the bars are scaled so that the sum of the squares of the bar levels is equal to 1). Only the **direction** of the component vector is important, so one should focus only on the relationship between the values and not the numerical values of the levels. For example, relative to the bars in the figure showing the **2nd** principal component, the bars in the figure representing the **1st** component are **almost all the same**. In the side-by-side figures below, we show two representations of the same principal component data. The heights of the bars in the barplots on the right correspond to the colors of the tiles in the gridplots on the left. In the barplot, there is one bar for each option structure, or point on the volatility surface, and in the gridplot there is one tile for each structure.

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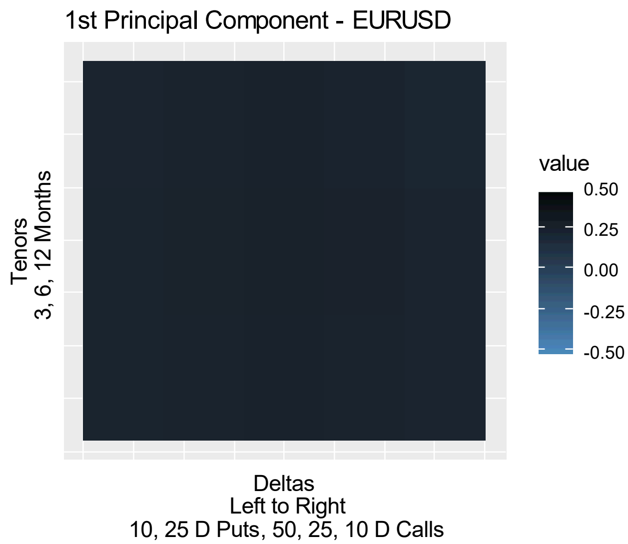
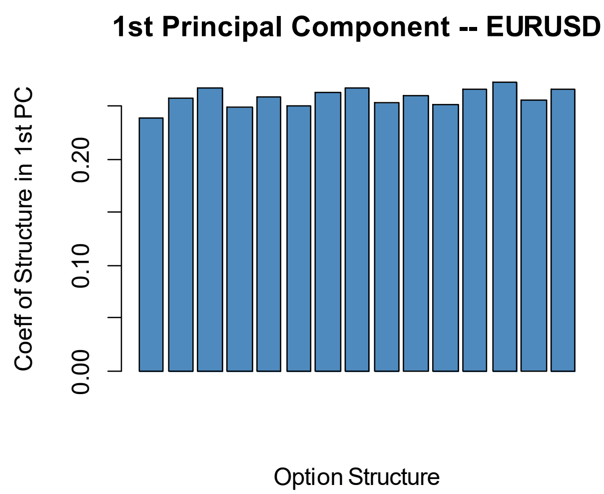
Figure 2: 1st Principal Component



Source: J.P. Morgan.

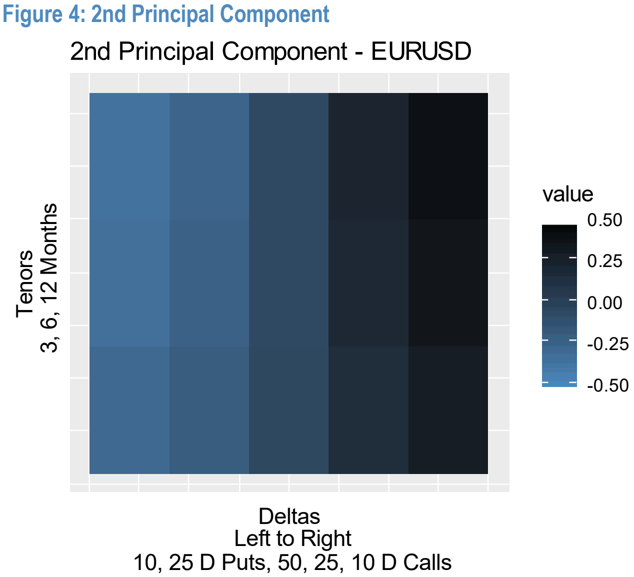
Figure 3: 1st Principal Component



Source: J.P. Morgan.

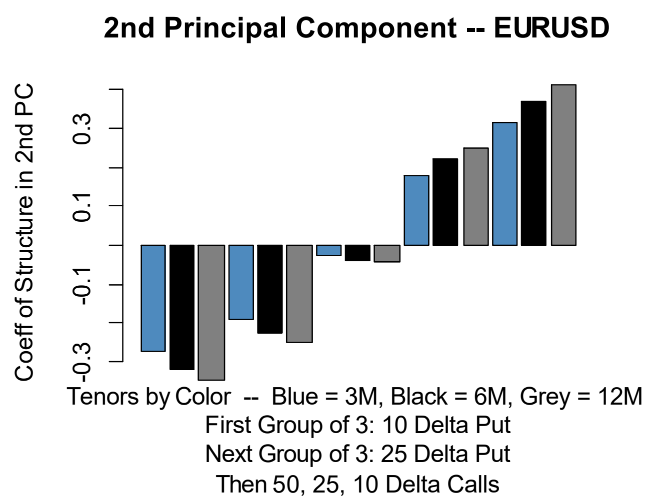
The meaning of having all nearly equal bars in the **PC1** bar plot is that most of the movement of the volatility surface is characterized by all of the volatility values moving together. This is often known as the **parallel shift component**. The next plot shows a more interesting variation in the surface, which depends on both the strike and the tenor level.

Figure 4: 2nd Principal Component



Source: J.P. Morgan.

Figure 5: 2nd Principal Component



Source: J.P. Morgan.

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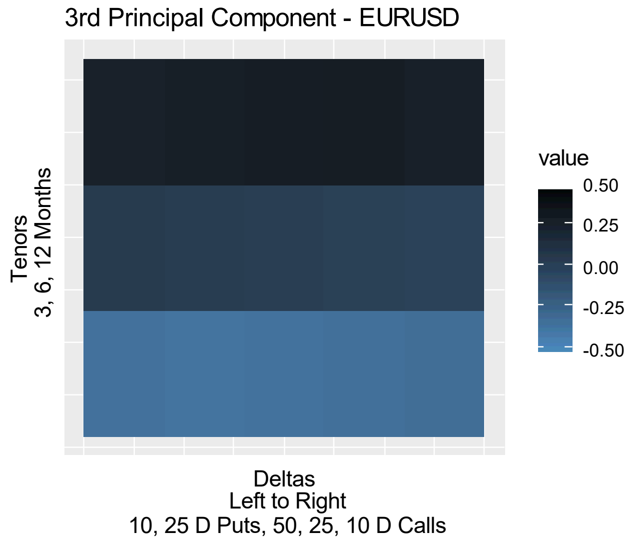
The bar plot for **PC2** (which contains roughly **10%** of the variation in this example) shows the **skew** of the surface. For example, consider the **blue** bars, which represent the **3M** tenors along the different strikes. The leftmost blue bar has the opposite sign of the rightmost blue bar, which means that **changing the value of the second principal component corresponds to** increasing the vol level at the 3M 10 Delta Put level and decreasing the vol level at the 3M 10 Delta Call level by approximately the same amount.

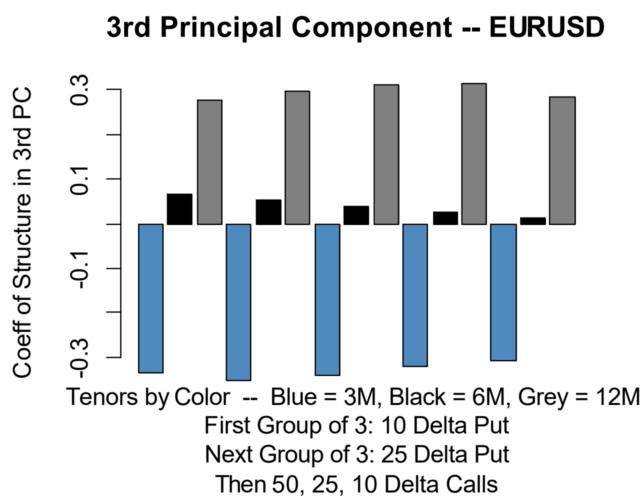
In the next example below, we examine the **third** principal component of the **EUR/USD** surface.

Figure 6: 3rd Principal Component



Source: J.P. Morgan.

Figure 7: 3rd Principal Component



Source: J.P. Morgan.

In this figure, the blue and gray bars have opposite signs. This shows us that this component corresponds to the dynamics of the **slope of the term structure**. Recall that we are using the z-scores of the volatility levels. In other words, as we move along the direction of the third component we move from (1) to (2):

1) The shorter tenors having a relatively **high** volatility level compared with their own history and the longer-term tenors having a relatively **low** volatility level compared with their own history.

2) The shorter tenors having a relatively **low** volatility level compared with their own history and the longer-term tenors having a relatively **high** volatility level compared with their own history.

Model Construction

Above we looked at the dynamics of the volatility surface. Now we investigate how changes in the shape of the surface affects the future PnL of different option structures. In particular, we consider delta hedged option structures and train a model that predicts their PnL based on the values of the first **five** principal components of the surface.

We train a separate support vector machine (**SVM**) with a radial basis function for each currency and each option structure using the following variables:

Independent Variables: The values of the first 5 principal components of the respective volatility surface.

Dependent Variable: The PnL from holding the option structure for 1 month with daily delta hedging.

In other words, we have:

$$svm(P\&L \sim PC1 + PC2 + PC3 + PC4 + PC5)$$

We use a training period from **April 2010 to Jan 2014** and a test period from **Jan 2014 to present.** We are using a 1-month holding period because a longer period will result in more noise due to the quickly changing components.

We use the model PnL predictions for each of the delta-hedged options to build a portfolio of option structures. We refer to these by $\boldsymbol{m_i}$ where $\boldsymbol{i}$ is an index referring to one of the nodes of the volatility surface. We choose our portfolio weights in the following way:

1. We start by taking the weights w_i to be equal to m_i

2. We next subtract the average of the weights (or prediction) vector. This is because the model predictions tend to favor selling volatility, and we would like our strategy to have a low correlation with a general volatility selling strategy.

3. Next we resize the weights by taking $w_i = \frac{c * w_i}{\sqrt{\boldsymbol{w}^{\boldsymbol{T}} \boldsymbol{S} \, \boldsymbol{w}}}$ for each i, where **S** is the covariance matrix of the delta hedged PnLs from the options during the training period. This resizing attempts to keep a fixed standard deviation of returns. We arbitrarily choose $\boldsymbol{c}$ to be equal to 0.01 in order to aim for a standard volatility of **1%** for each trade. This gives us the final strategy weights.

Model Statistics

Here we show the regression coefficient of the SVM predicted PnL vs the actual PnL for each of the currencies. Note that we have fit a **different model for each option structure and for each currency**. We also note here that for the **50 Delta** option PnLs we use the average of the puts and calls, i.e., half of a straddle.

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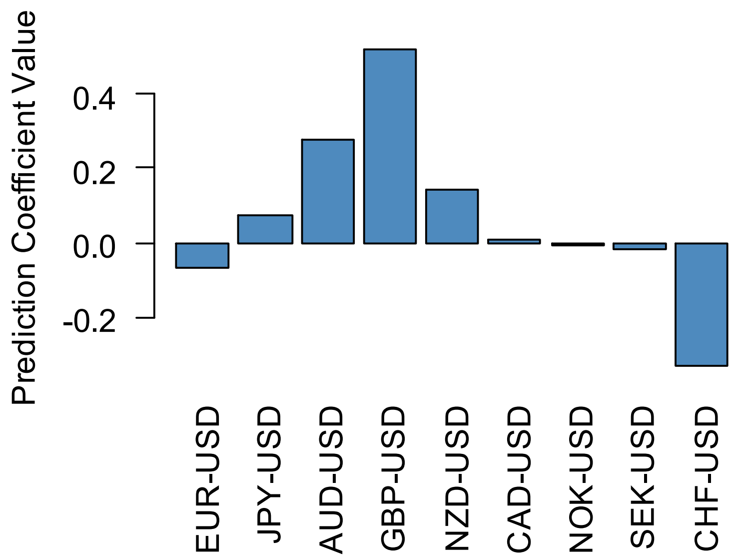
Figure 8: Beta of Predicted PnL to Actual PnL



Source: J.P. Morgan.

We consider the correlation between this strategy and a simplified sell volatility strategy so that we can make sure that any returns from this strategy are not just coming from the volatility risk premium. We compute the correlation between our returns and the returns of a strategy that just sells volatility on each structure with equal notional and holds for **1M**, delta hedged daily. Below we graph the correlations for each currency.

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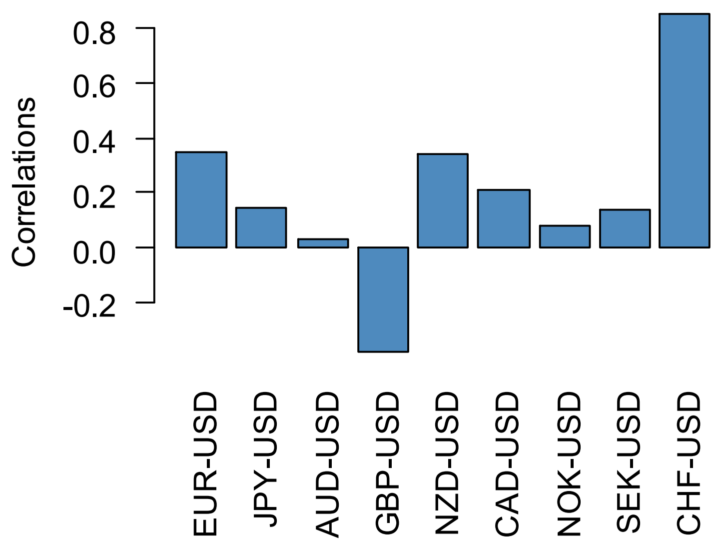
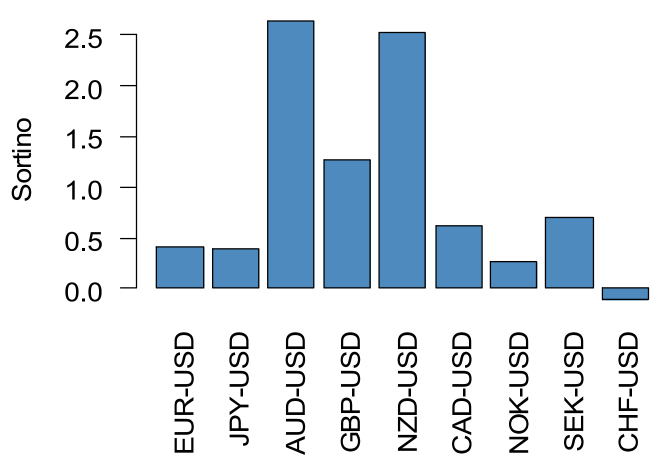
Figure 9: Correlations between Strategy and Sell-Vol Strategy



Source: J.P. Morgan.

Below we show the Sortino ratios of the strategy for each of the currencies. The numbers for **AUD/USD** and **NZD/USD** are both extremely high, but due to how similar their charts are we may want to only consider this to be just a single data point. We also calculated the Sortino ratios using a linear model instead of our SVM model as well as the Sortino ratio of the short vol strategy. The Sortino ratios of the SVM strategy, linear model strategy, and short vol strategy were **0.97, 0.91 and 0.91**, respectively.

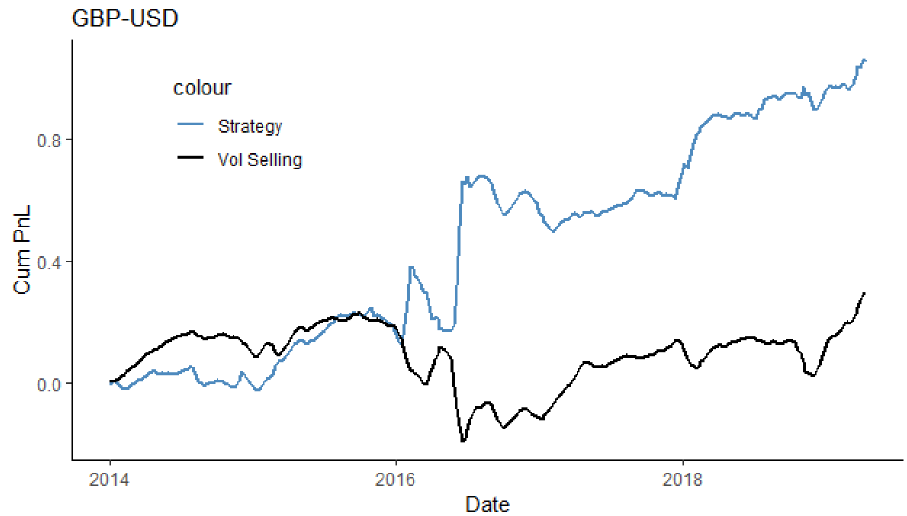
Figure 10: Sortino Ratios



Source: J.P. Morgan.

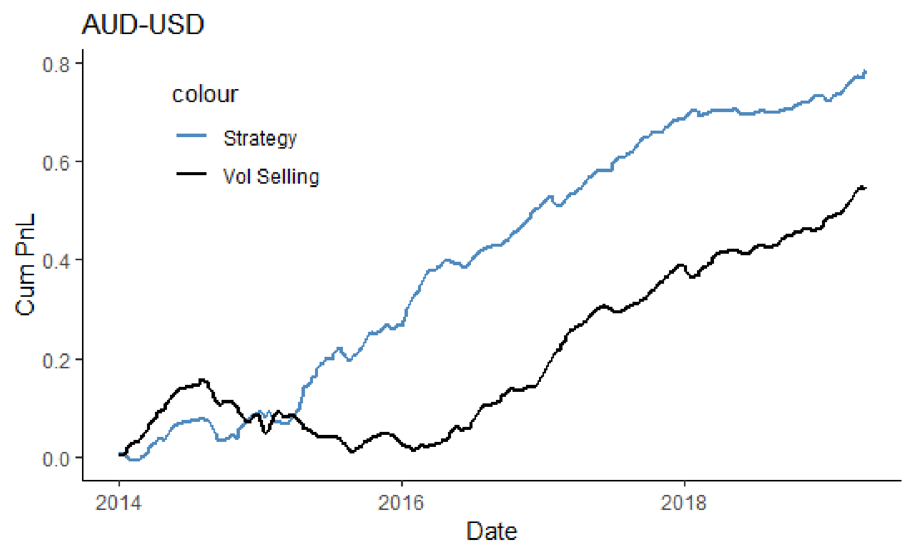
Below we show the PnL curves for a few of the best-performing currency pairs. The blue line is the strategy curve and the black line is the **PnL** of the simple volatility selling strategy. The black line is not really a benchmark but is included just for a comparison.

Figure 11: GBP P&L vs Volatility Selling



Source: J.P. Morgan.

Figure 12: AUD P&L vs Volatility Selling



Source: J.P. Morgan.

Current Model Output

The table below shows the expected **PnL in Basis Points** for the option structures, delta hedged daily with a 1M holding period. The numbers are mostly negative

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because these trades represent buying volatility. To get the numbers for selling the structures one can flip the sign on the numbers below.

Figure 13: Current Model Output

Vol Surface PnL Predictions in Basis Points 2019-06-27

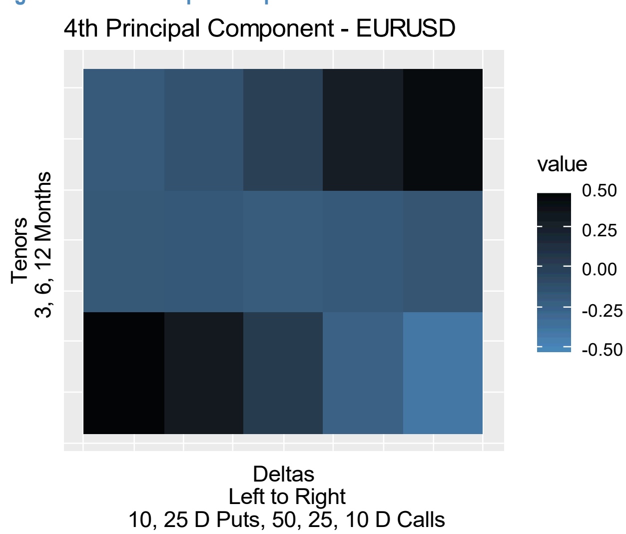
	ccy	3Mp25	3Ms50	3Mc25	6Mp25	6Ms50	6Mc25	12Mp25	12Ms50	12Mc25
1	AUD-USD	-39	-41	-29	-39	-43	-30	-39	-41	-31
2	CAD-USD	1	9	4	4	13	9	10	24	18
3	CHF-USD	-7	-13	-16	-8	-14	-17	-10	-16	-15
4	EUR-USD	-7	-5	-6	-4	-4	-7	-1	-8	-8
5	GBP-USD	-13	-9	-6	-10	-8	-5	-8	-7	-6
6	JPY-USD	-23	-26	-24	-21	-23	-20	-18	-23	-19
7	NOK-USD	-39	-51	-47	-49	-76	-64	-54	-85	-75
8	NZD-USD	-51	-47	-28	-54	-57	-32	-52	-52	-31
9	SEK-USD	-29	-36	-27	-30	-37	-25	-25	-39	-22

Source: J.P. Morgan

Appendix / Additional Components (4th and 5th Principal Components)

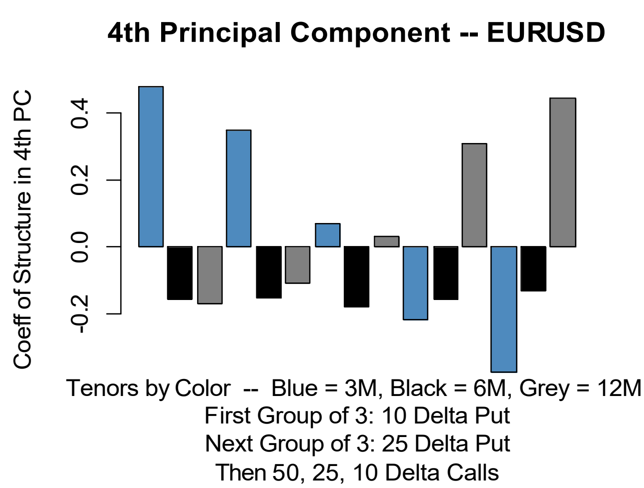
Here we present the 4th and 5th principal components of the **EUR/USD** volatility surface. When looking at the scree plot on the front page it may seem like these components are not important because they have low variation. However, the size of the variation of the principal components does not suggest anything about their respective predictive powers. The reason that we produce the first five components here is that they are economically intuitive. We find that it is difficult to assign much meaning to the components beyond the first five.

Figure 14: 4th Principal Component



Source: J.P. Morgan.

Figure 15: 4th Principal Component



Source: J.P. Morgan.

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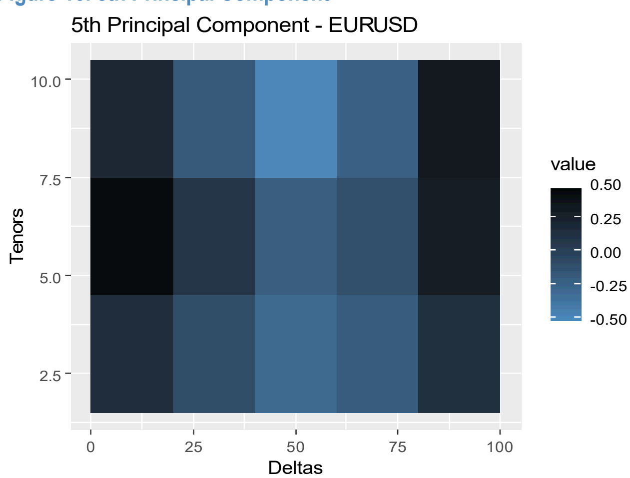
The fourth component can be understood as a measure of relative skew in the front tenors vs. the back tenors. We can think of this as **skew twist** in the surface. Notice how the blue bars are **monotonically decreasing** while the gray bars are **monotonically increasing**. In other words, as we move in the direction of the 4th principal component we have a larger difference between the skews of the opposing tenors. Note that since the sign of the principal component is not important, we are more concerned with the fact that one of these is strictly decreasing and one is increasing and not necessarily which tenor has the increasing bars.

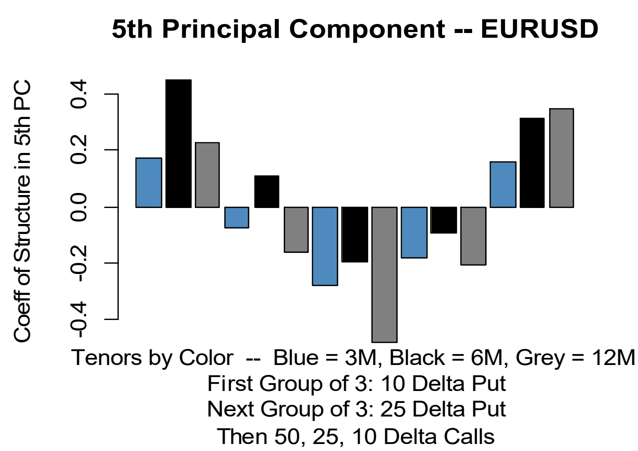
Finally we present the 5th component, which we interpret as the **convexity of the implied volatilities along the strikes, or the smile component.** Notice how for each color (tenor) the values form a parabola along the strikes. Therefore, as we move along the positive direction of the 5th component, we will get a steeper smile for each tenor.

Figure 16: 5th Principal Component



Source: J.P. Morgan.

Figure 17: 5th Principal Component



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