Foreign Exchange: Markets, Products, and Pricing

Winter Quarter 2023

Week #4

Problem #21 Is this a derivative?

- Assume the FX spot rate, S, follows geometric Brownian motion
- Let V be a very simple derivative contract based on S, where
  - $V(S_t, t) = S_t$ at any time, t
  - In other words, the derivative V always has value equal to the spot rate at the then-current time
- Does the argument in the section "Valuing FX options" of the week #3 lecture notes apply to the function V described above?

Problem #23 Option Hedge

- Assume that a USD-based bank buys the following option (from a client)
  - USD call / JPY put, strike 120.00, notional USD 100 million
- If the current trading day is one day before the option's maturity and the current spot rate is 131.87, then what size of spot transaction should the bank execute in order to hedge the value of the purchased option against movements in the exchange rate?

Delta

Delta (Black-Scholes Formula)

- Sensitivity of the option's value to changes in the FX spot rate
- Black-Scholes formula

$$\boldsymbol{Bl}(S, t, T, K, P^d, P^f, \sigma, \omega) = P^d\, \omega\, [\, F\, \Phi(\omega d_1) - K\, \Phi(\omega d_2)\,]$$

$d_{1,2}$ = log(F/K) / $\sigma\sqrt{(T-t)}$ +/- $0.5*\sigma\sqrt{(T-t)}$

ω = 1 denotes call, and -1 denotes put

$\Phi(*)$ denotes the standard normal cumulative density function

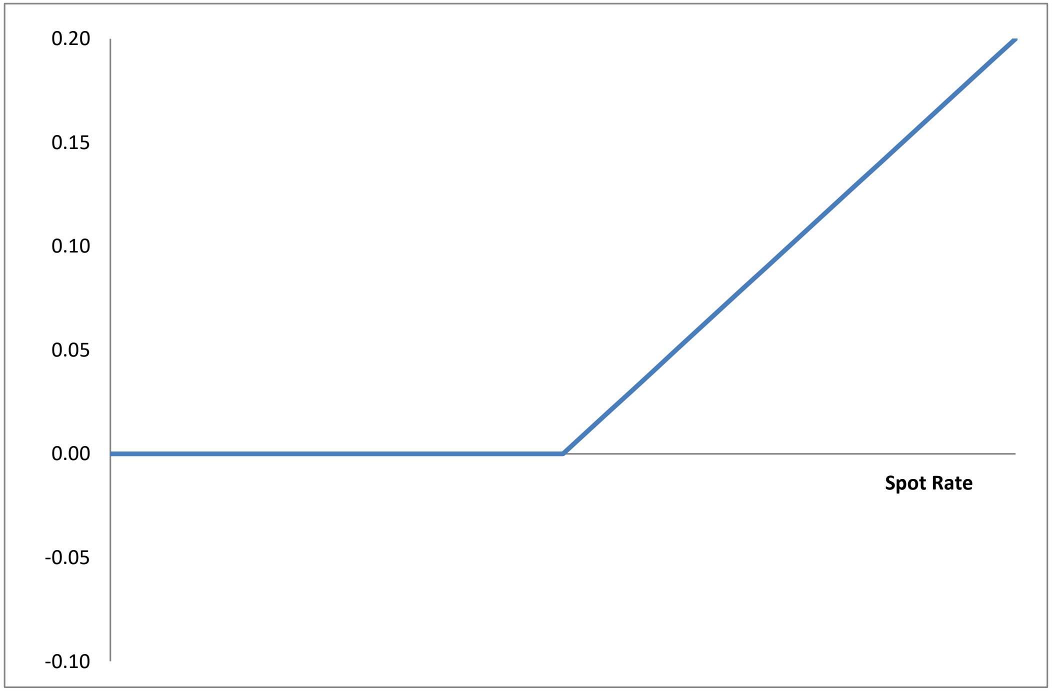
- Can re-write the formula as

$$\boldsymbol{Bl}(S, t, T, K, P^d, P^f, \sigma, \omega) = \omega\, P^f\, S\, \Phi(\omega d_1) - \omega\, P^d\, K\, \Phi(\omega d_2)$$

- Formula for delta

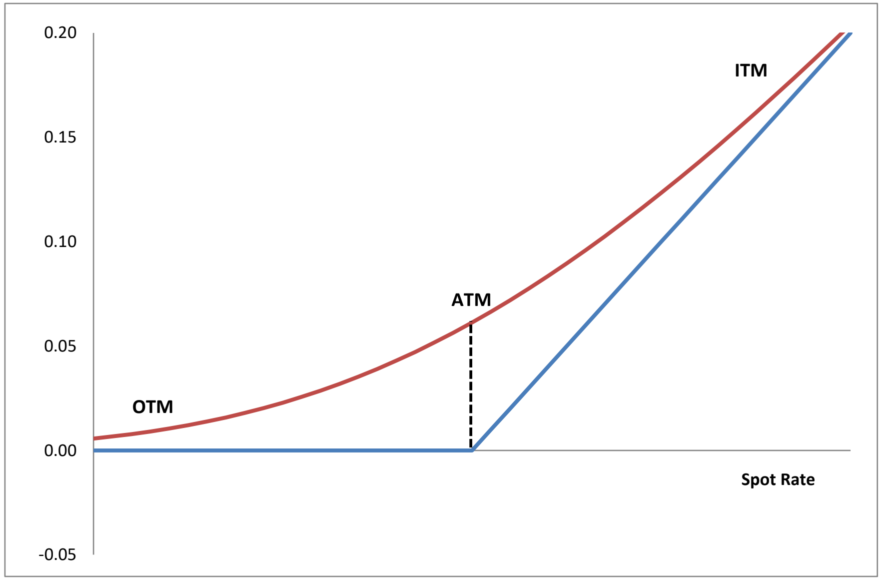
$$\boldsymbol{\Delta} = \partial \boldsymbol{Bl} / \partial S = \omega\, P^f\, \Phi(\omega d_1)$$

Delta of a call option at maturity



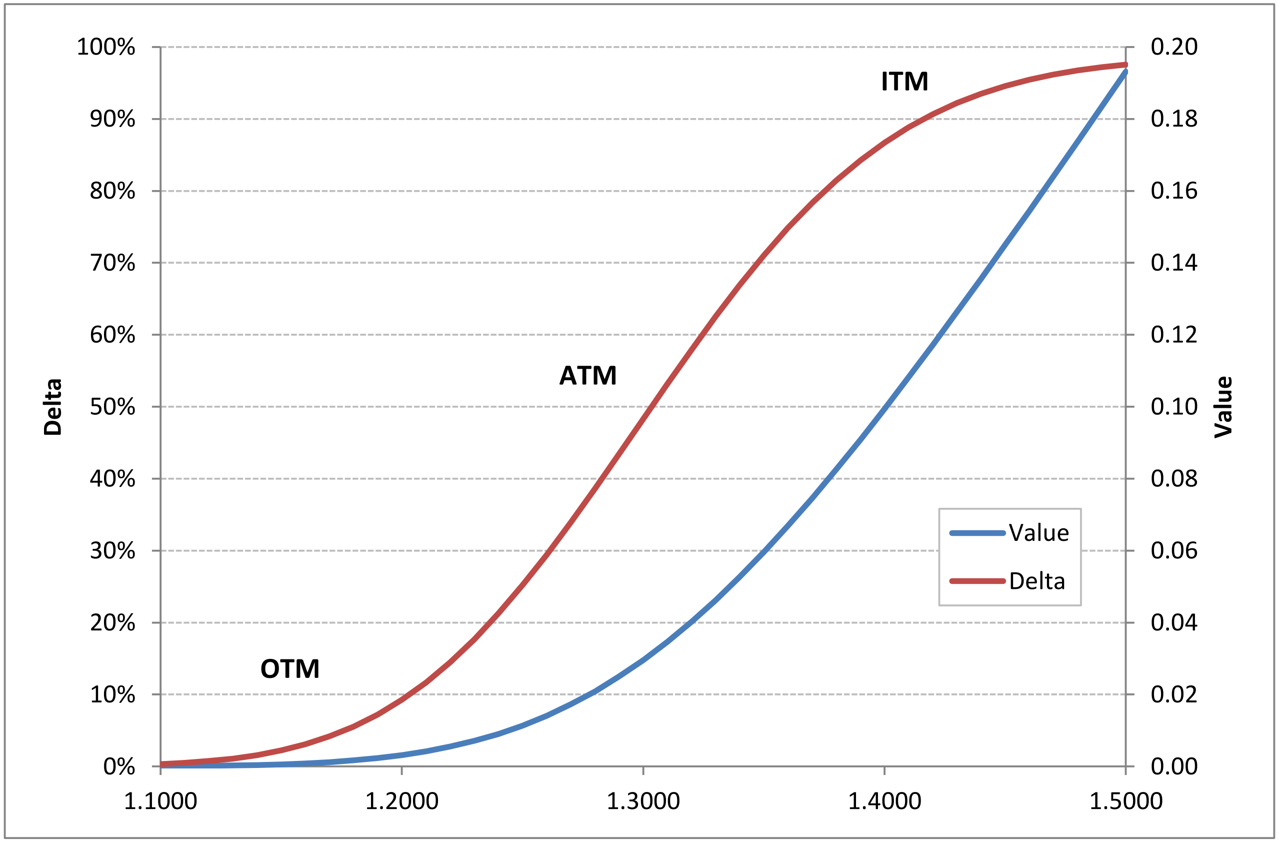
Delta of a call option prior to maturity

- EUR call USD put
- 1 year to maturity
- Volatility = 12.4%



Delta for different values of spot

- Delta generally ranges between 0% and 100%



Delta hedging in practice

- Delta gives the amount of a spot position (in the base currency) that is equivalent to a position in the option
- -1 * Delta is the amount of underlying FX that should be held to hedge the value of the option
  - For small changes in spot the gain or loss on the option position will be offset by an opposite loss or gain on the underlying (delta hedge)
- In practice delta hedging is not done continuously
  - Usually at pre-set intervals as the spot rate moves

Delta hedging in practice (continued)

- End-users will typically purchase (or sell) options with no delta hedge
- Option trades between two dealers almost always include a delta exchange
  - The dealers agree to option terms: spot, forward, volatility and therefore price
  - The delta hedge is exchanged between dealers at the referenced spot rate

Delta: Quoting Conventions

- Delta can be calculated from either the terms currency viewpoint or the base currency viewpoint
  - For calls and puts $P_{d/f}$ and $P_{f\%}$ are the relevant price quotes
- Premium Adjustment
  - Additional risk when the premium is set in a currency different from the investor's currency
- Spot Delta or Forward Delta
  - $\boldsymbol{\Delta_S} = \partial P / \partial S \quad \boldsymbol{\Delta_F} = \partial P / \partial F$

Delta: Domestic Currency Viewpoint

- The amount of base currency spot equivalent to the option
  - Terms currency investor's viewpoint. How much base currency to hold, for an option on 1 unit of base currency
  - This is the delta resulting from the Black-Scholes formula

"Pips Spot Delta" (also called "Points Spot Delta")

$$\boldsymbol{\Delta}_{S,d/f} = \partial P_{d/f} \,/\, \partial S = \partial\, \boldsymbol{BI} \,/\, \partial S = \omega\, P^f\, \Phi(\omega d_1)$$

- Example of when Pips Spot Delta is used:
  - Option on EURUSD for a USD investor, where the premium is paid in USD
  - In general, for options quoted as $P_{d/f}$ (premium paid in terms ccy)

Premium-included Delta

- Domestic currency (terms currency) viewpoint
- If premium is paid in base currency, then the premium payment represents additional FX risk from the terms currency viewpoint
- Premium-included delta

$$\mathbf{\Delta}^{pi} = \mathbf{\Delta}_{S,d/f} - P_{f\%}$$

- Example of when Premium-included Delta is relevant:
  - Option on USDJPY for a JPY investor, where the premium is paid in USD
  - In general, for options quoted as $P_{f\%}$ (premium paid in base currency)

Delta: Foreign Currency Viewpoint

- Referred to as “Percentage Spot Delta”
- The amount of base currency spot equivalent to the option
  - Base currency investor’s viewpoint. How much base currency to hold for an option on 1 unit of base currency
- Note the two differences
  - This is not simply switching to a base currency inventor’s viewpoint
  - It is also calculating how much base currency to hold and using 1 unit of base currency as the option amount

Percentage Spot Delta (definition)

- $\boldsymbol{\Delta}_{S,f\%} = -S^* \partial P_{f\%} / \partial S^*$, *where* $S^* = 1/S$
- Why?
  - $\partial/\partial S^*$ because it gives the base currency investor's viewpoint
  - $\partial P_{f\%}/\partial S^*$ because it gives the amount of terms currency spot equivalent for base currency investor
  - $-S^* \partial P_{f\%}/\partial S^*$, because we want the amount of base currency in the equivalent spot position, and buying $\partial P_{f\%}/\partial S^*$ of terms currency spot means selling $S^* \partial P_{f\%}/\partial S^*$ of base currency

Percentage Spot Delta (calculation)

- $\boldsymbol{\Delta}_{S,f\%} = \; - S^* \,\partial P_{f\%}/\partial S^*$, *where* $S^* = 1/S$

  Note that $P_{f\%} = \; S^* \,\boldsymbol{BI}(1/S^*)$

  $- S^* \,\partial P_{f\%}/\partial S^* = - S^* \,\partial/\partial S^* \,[S^* \,\boldsymbol{BI}(1/S^*)\,]$

  $= - S^* \,[\,\boldsymbol{BI}(1/S^*) - S^* \,(S^*)^{-2} \,\partial/\partial S^* \,\boldsymbol{BI}(S^*)\,]$

  $= - S^* \,[\,P_{d/f} - S \,\boldsymbol{\Delta}_{S,f/d}\,]$

  $= \boldsymbol{\Delta}_{S,d/f} - P_{f\%}$

- This calculation shows that $\boldsymbol{\Delta}_{S,f\%} = \boldsymbol{\Delta}^{pi}$

% Spot Delta = Premium-Included Delta

- Our calculations show that $\mathbf{\Delta}_{S,f\%} = \mathbf{\Delta}_{S,d/f} - P_{f\%} = \mathbf{\Delta}^{pi}$

Which form of delta is relevant?

- For options quoted as $P_{f\%}$ (premium paid in base ccy)
  - Terms ccy investor wants $\mathbf{\Delta}^{pi}$
  - Base ccy investor wants $\mathbf{\Delta}_{f\%}$, which equals $\mathbf{\Delta}^{pi}$
- For options quoted as $P_{d/f}$ (premium paid in terms ccy)
  - Terms ccy investor wants $\mathbf{\Delta}_{d/f}$
  - Base ccy investor wants $\mathbf{\Delta}_{f\%}$ adjusted for premium, which has a positive base currency spot equivalent (pay terms currency means receiving base currency)
    - $\mathbf{\Delta}_{f\%} + P_{f\%} = \mathbf{\Delta}_{d/f} - P_{f\%} + P_{f\%} = \mathbf{\Delta}_{d/f}$

Quoting Conventions

Table 3.1 Delta conventions for common currency pairs

Currency pair	ccy1	ccy2	Premium ccy	Δ convention
EURUSD	EUR	USD	USD	Pips
USDJPY	USD	JPY	USD	%
EURJPY	EUR	JPY	EUR	%
USDCHF	USD	CHF	USD	%
EURCHF	EUR	CHF	EUR	%
GBPUSD	GBP	USD	USD	Pips
EURGBP	EUR	GBP	EUR	%
AUDUSD	AUD	USD	USD	Pips
AUDJPY	AUD	JPY	AUD	%
USDCAD	USD	CAD	USD	%
USDBRL	USD	BRL	USD	%
USDMXN	USD	MXN	USD	%

Percentage Spot Delta (another calculation)

- Base currency investor's viewpoint using the Black-Scholes formula

$$\Delta_{S,f\%} = -S^* K\, \partial \boldsymbol{BI}(\underline{S^*}, t, T, \underline{1/K}, \underline{P^f}, \underline{P^d}, \sigma, \underline{-\omega})/\partial S^*, \text{ where } S^* = 1/S$$

- Since $\partial \boldsymbol{BI}(\underline{S^*}, t, T, \underline{1/K}, \underline{P^f}, \underline{P^d}, \sigma, \underline{-\omega})/\partial S^* = -\omega P^d\, \Phi(\omega d_2)$
- $\Delta_{S,f\%} = \omega\, (K/S)\, P^d\, \Phi(\omega d_2)$

Percentage Spot Delta formulas

$$\Delta_{S,f\%} = \Delta_{S,d/f} - P_{f\%}$$

$$\Delta_{S,f\%} = (K/S)\, \omega\, P^d\, \Phi(\omega d_2)$$

Gamma

Gamma

- As illustrated on previous slides, delta changes as the spot rate changes
- With forward positions, this is not true:
  - No optionality implies no change in delta
- Gamma
  - Second derivative, or curvature, of the value function
    - Theoretical: $\partial^2 P / \partial S^2$
    - Practitioner: $\Delta^2 P / \Delta S^2$
  - Practitioner's definition: "Change in delta / small change in FX rate"
  - Most common units: "Percent change in delta / 1% move in spot"

Gamma

- Interpretation
  - Gamma indicates how much to adjust the FX rate hedge to remain "delta neutral"
  - Higher gamma implies faster changes in delta
  - Positive gamma: "increasing delta as the market increases"
    - Is this valuable?

Gamma (Black-Scholes Formula)

- Gamma $\partial^2 \boldsymbol{BI} / \partial S^2$
  - $\boldsymbol{\Gamma} = \partial^2 \boldsymbol{BI} / \partial S^2 = P^f \; \Phi'(d_1) / (S \, \sigma \sqrt{(T-t)})$

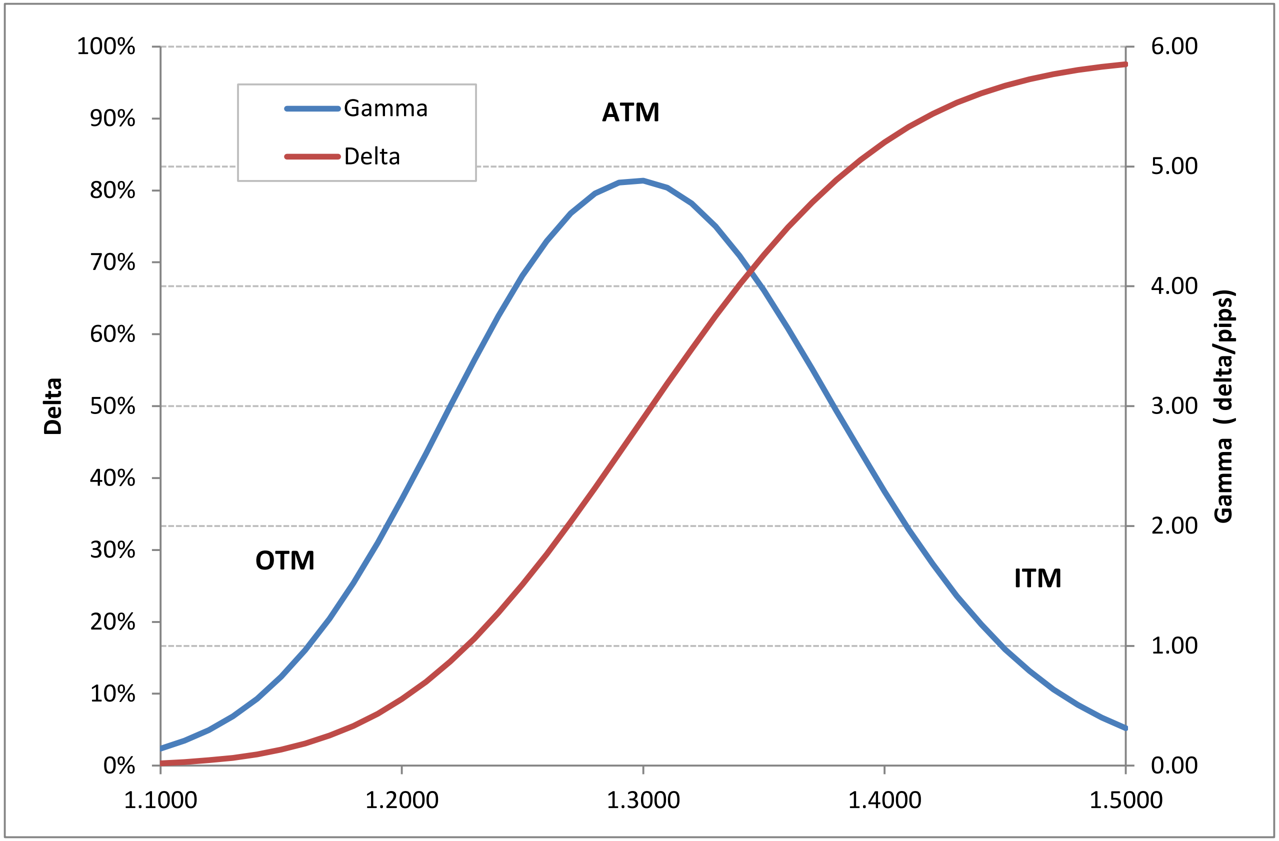
  where Φ'() is the standard normal density

- *"Trader's Gamma"*
  - *Usually scaled to a 1% move in the spot rate (i.e., change in Delta for a 1% change in Spot)*
  - $\boldsymbol{\Gamma}^{\mathbf{tr}} = \boldsymbol{\Gamma} * (S/100)$

- Premium-included Gamma (used when premium is included in Delta, i.e., when base ccy is the viewpoint)
  - $\boldsymbol{\Gamma}^{\mathbf{pi}} = \Gamma - \Delta / S + 2 * 0.01 * P_{f\%} / S$

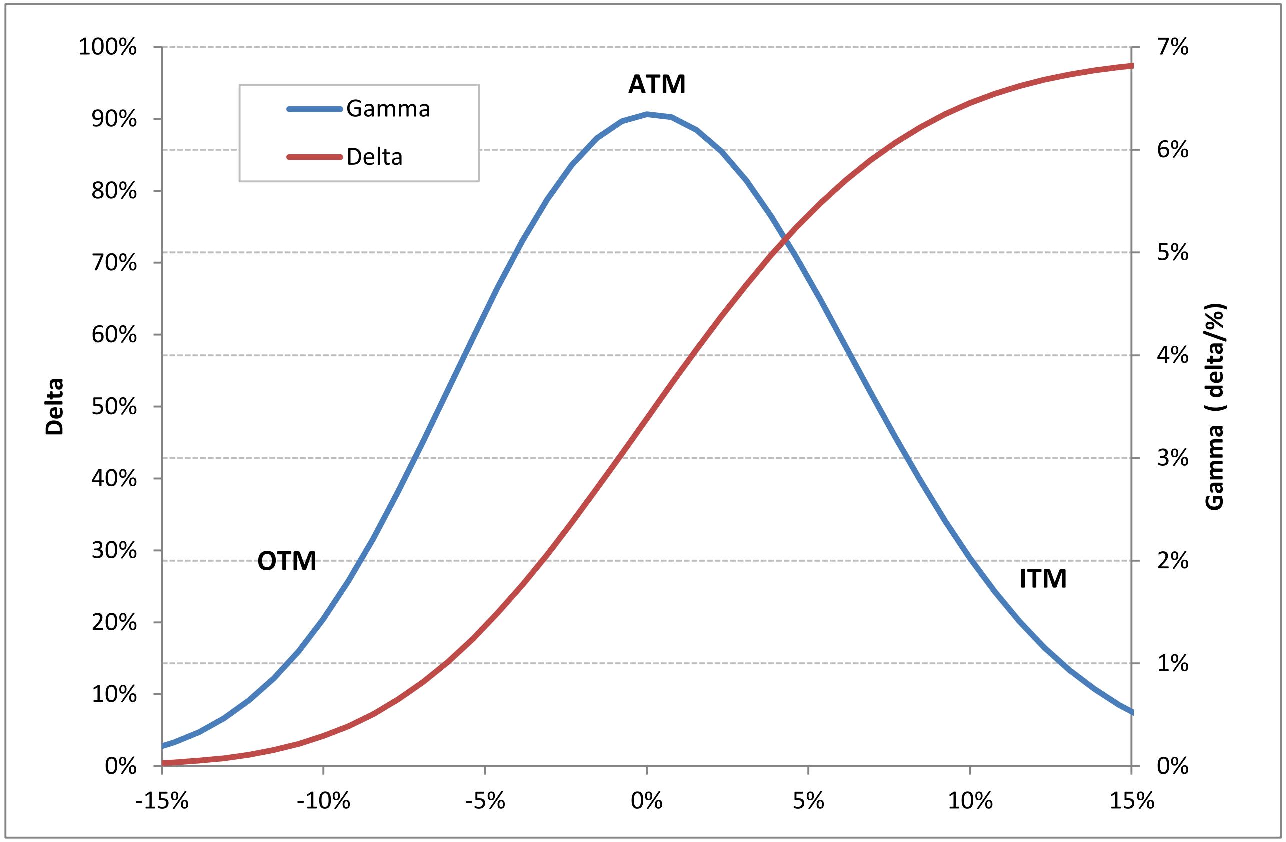
Gamma: what are the units?

- Standard formula: change in delta per “numeraire, pips” change in spot
- The value for 1 unit of base currency matters in the standard formula
- 5.00 means: ±5% in delta for ±0.01 of spot

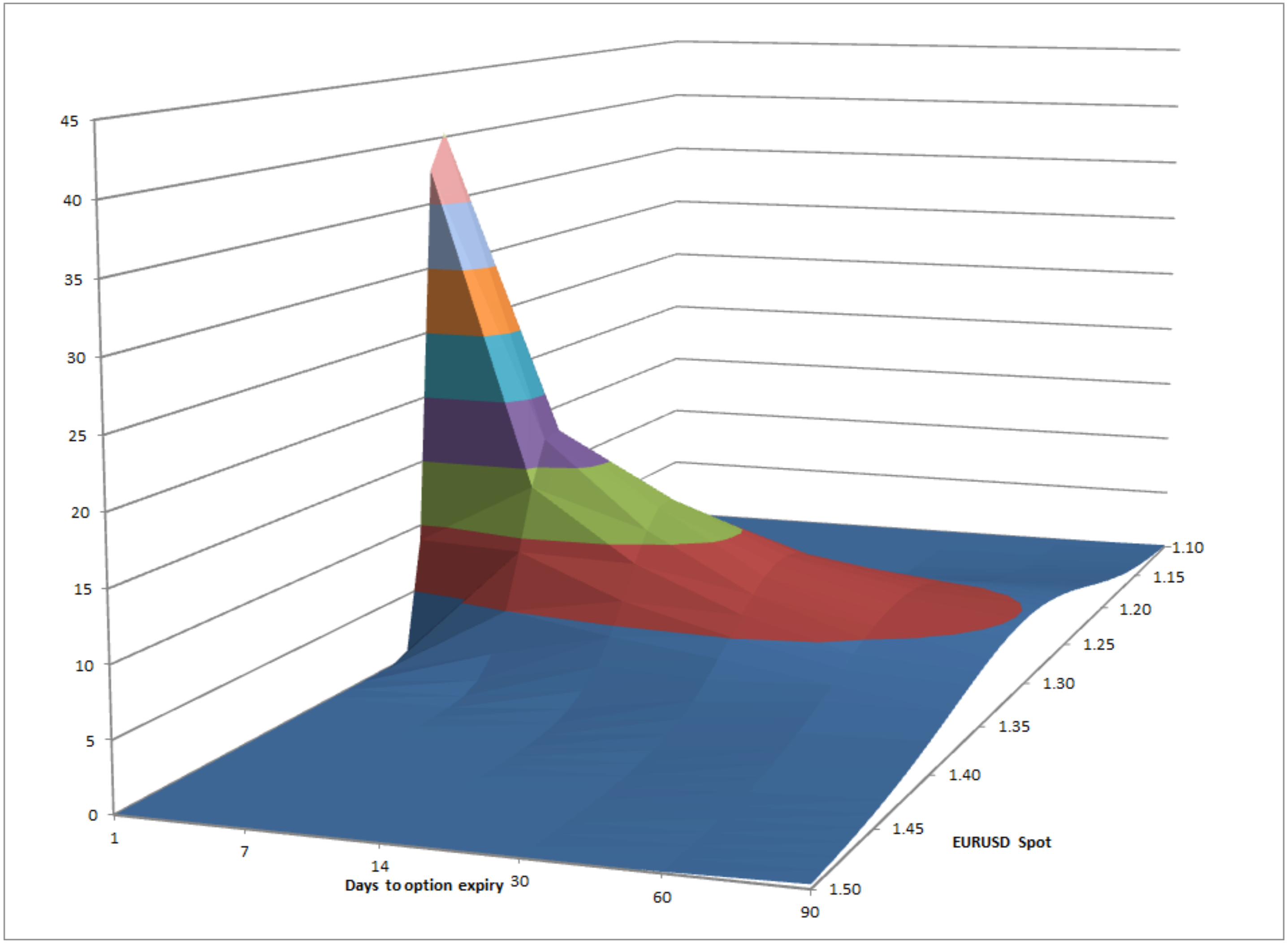


Gamma: what are the units?

- More useful measure is to scale Gamma by percent changes in spot
- 5% means: ±5% in delta for ±1% in spot



Gamma close to expiry

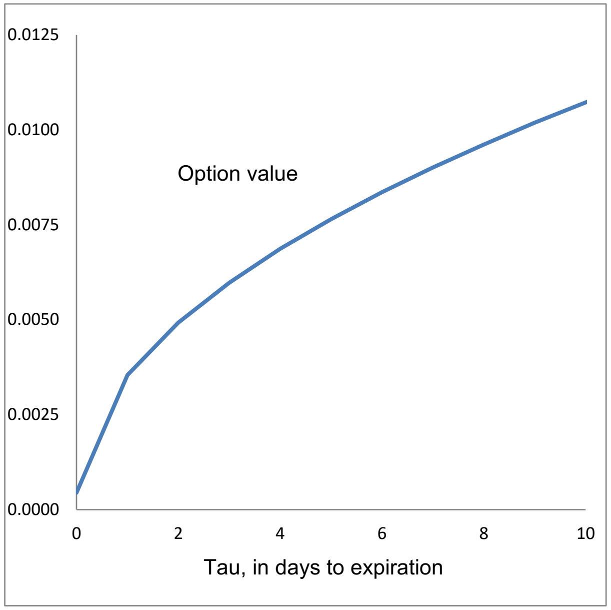


Theta

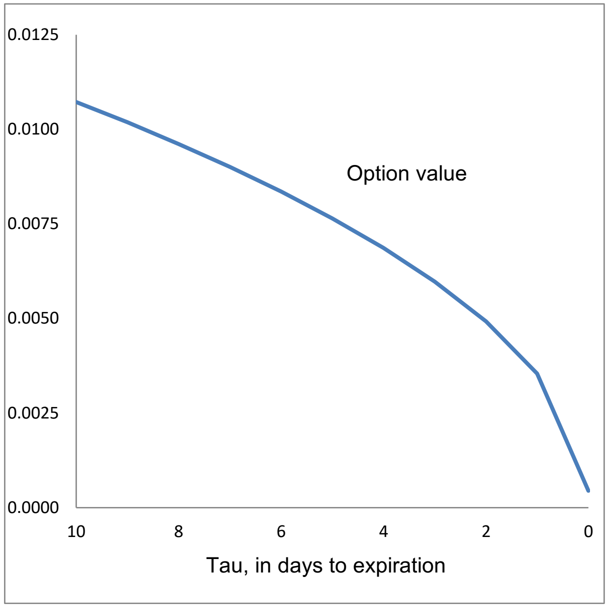
Theta

- Theta: $\partial P / \partial \tau$, where $\tau = T - t$, Practitioner's view: $\Delta P / \Delta t$
- If nothing changes except the passage of time, the value of an option drops
- The amount of option value that erodes with the passage of time
- Roughly a square root of time impact (for at-the-money options)

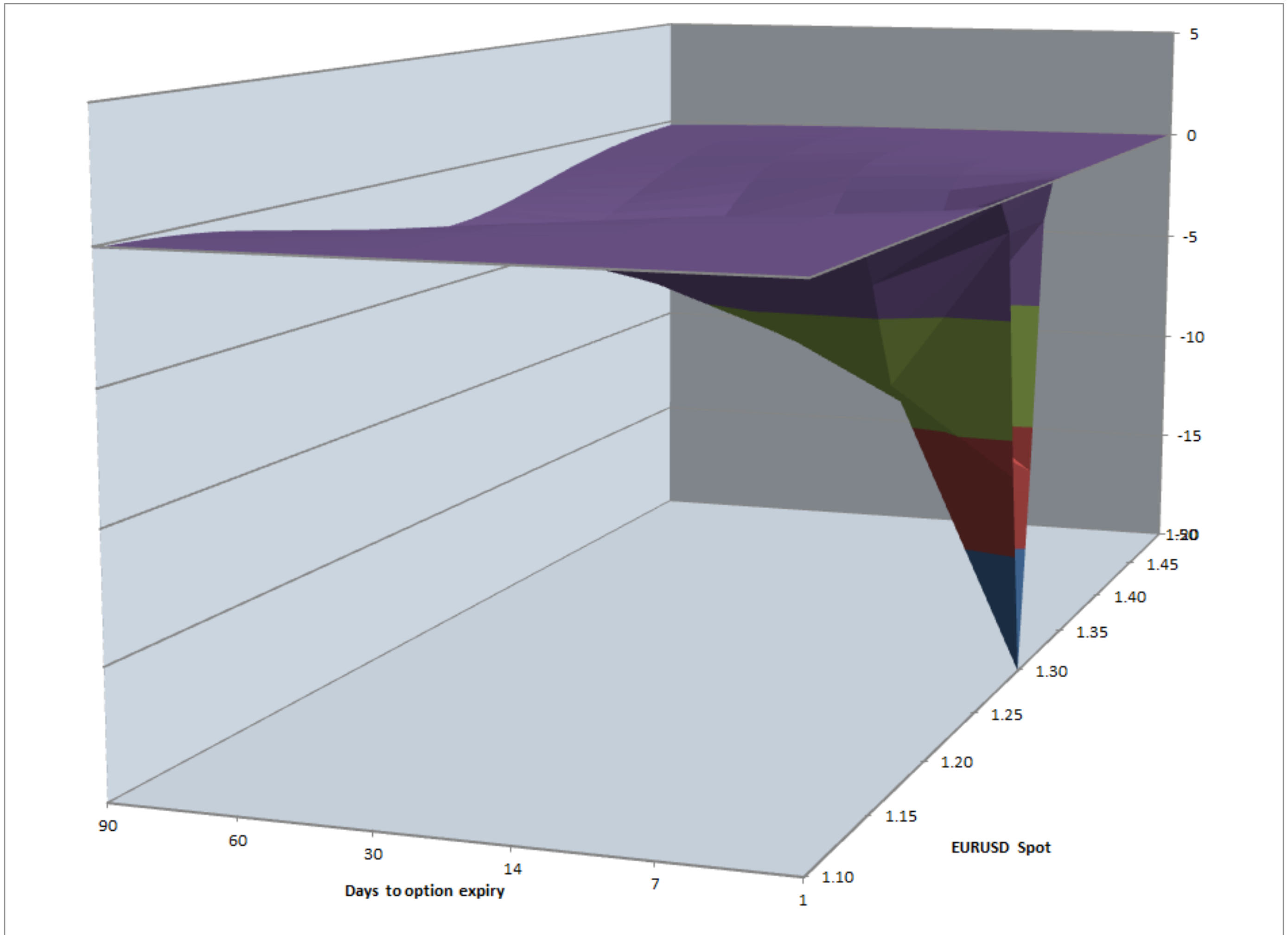
Academic view:
Time-to-expiration increasing (tau = T-t)



Trading view: calendar increasing (t)
Time-to-expiration decreasing (tau = T-t)



Theta



5
0
-5
-10
-15
-20
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
EURUSD Spot
90
60
30
14
7
1
Days to option expiry

Volatility Risk Measures

Things that aren’t supposed to happen under Black-Scholes

- “Practical” risk measures:
    - Vega
    - Vanna
    - Volga (“gamma of vega”, “GoV”)
- Not consistent with Black-Scholes assumptions
    - Highly used in practice

Vega

Vega (Black-Scholes Formula)

- Sensitivity of the option's value to changes in the volatility input, σ

  $\mathbf{V} = \partial \boldsymbol{BI} / \partial\sigma = P^f\, \Phi'(d_1)\, S_t \sqrt{(T-t)}$

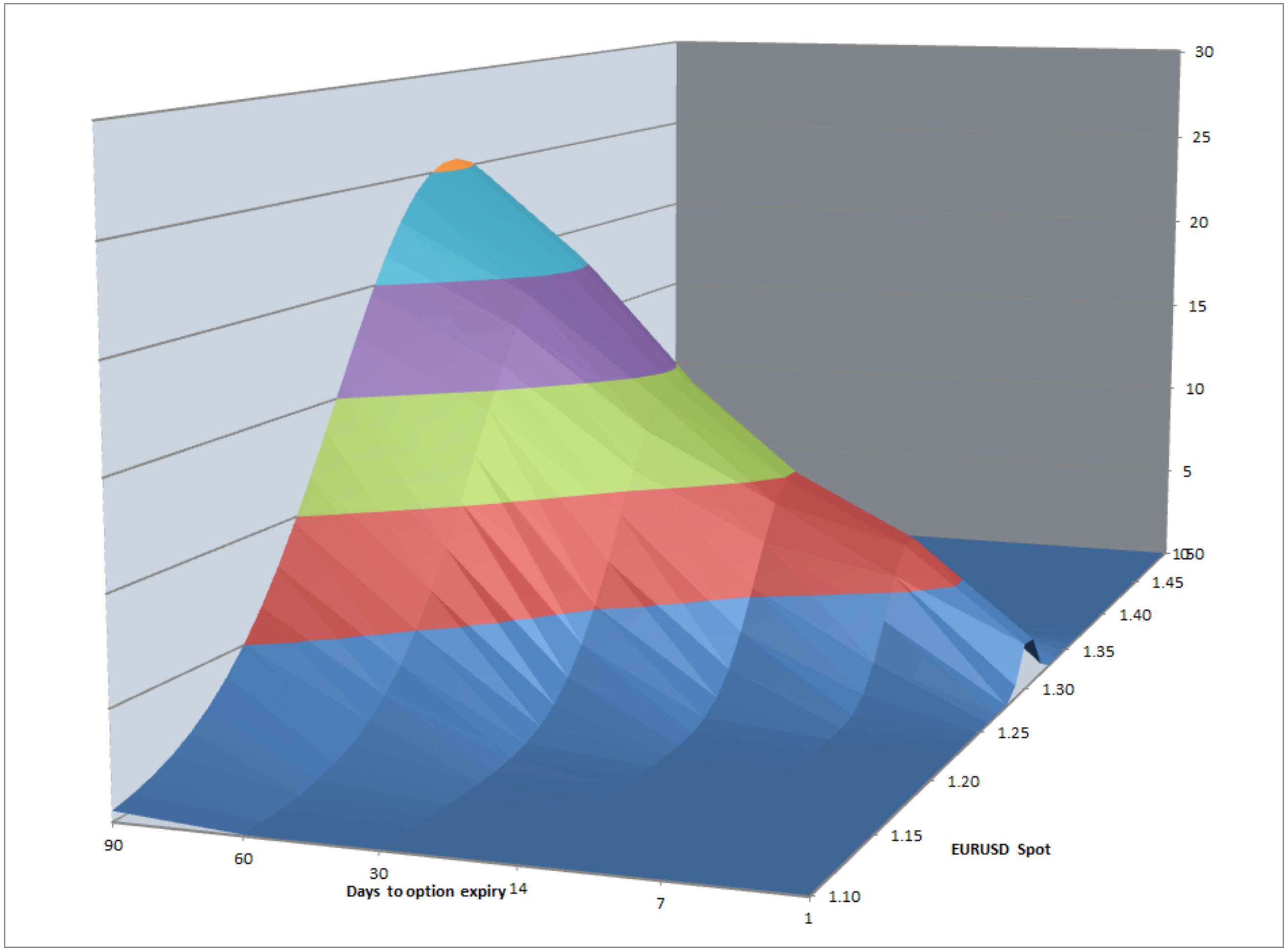
  where $\Phi'()$ is the standard normal density

  P^f = foreign discount factor, d_1 as in Black-Scholes

- Not consistent with Black-Scholes assumptions

- Practitioner measures a standard unit change: $\Delta P / \Delta\sigma$
  - Common to measure "1 vol", i.e., +/- 0.01 of the volatility input σ

Vega



30
25
20
15
10
5
0
90
60
30
14
7
1
Days to option expiry
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
EURUSD Spot

Vega-Gamma relationship

- $Vega = Gamma * S^2 * \sigma * (T - t)$

  Confirming this -

  - $Vega = [\, P^f\ \Phi'(d_1) / (S\ \sigma \sqrt{(T-t)})\,] * S^2 * \sigma * (T - t)$
  - $Vega = P^f\ \Phi'(d_1) * S * \sqrt{(T - t)}$

- $Gamma$ = Vega / $(S^2 * \sigma * (T - t))$

  Confirming this -

  - $Gamma = [P^f\ \Phi'(d_1)\ S \sqrt{(T - t)}\,] / (S^2 * \sigma * (T - t))$
  - $Gamma = P^f\ \Phi'(d_1) / (S\ \sigma \sqrt{(T - t)})$

Delta-Vega relationship

- Delta-Vega relationship
  - For a call and put with the same expiration, *T*
  - **Deltas** are equal (in absolute value) if and only if **vegas** are equal
  - Note that the call and put will generally have different strikes,
  - Call and put can have different implied volatility
  - Not true for premium-included delta

Vanna

Vanna

- Vanna $\partial^2 P / \partial\sigma\, \partial S$
  - $\mathbf{X} = \partial^2 \boldsymbol{BI} / \partial\sigma\, \partial S = -P^f\, \Phi'(d_1)\, d_2 / \sigma$

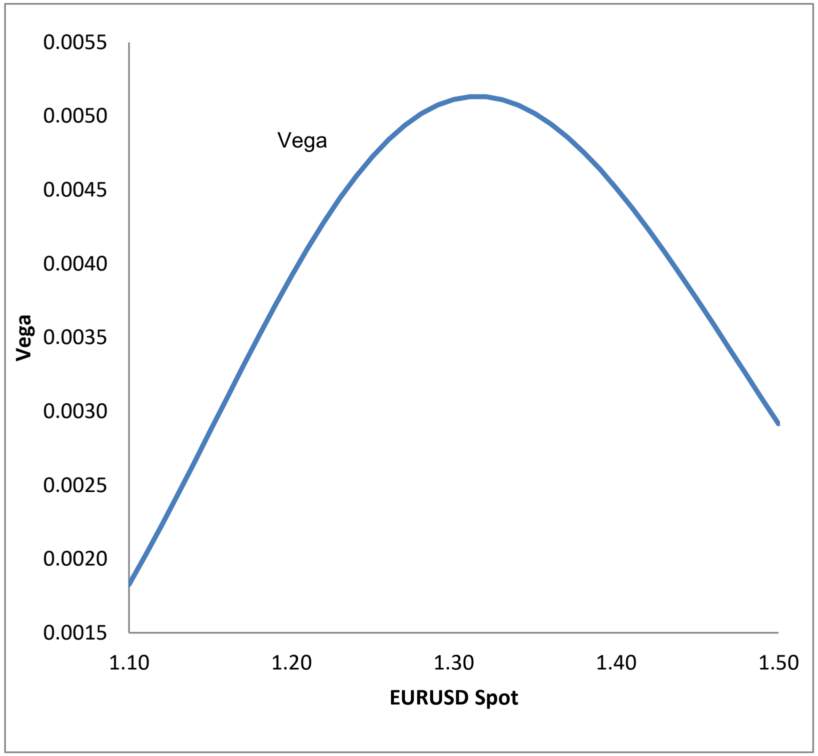
  where $\Phi'()$ *is the standard normal density*

- Premium-included Vanna (used when premium is included in Delta, i.e., when base currency is the viewpoint)

Vanna

- How does vega change as spot changes?
  - Theoretical: $\partial^2 P / \partial\sigma\, \partial S$
  - Practitioner: $\Delta^2 P / \Delta\sigma\, \Delta S$

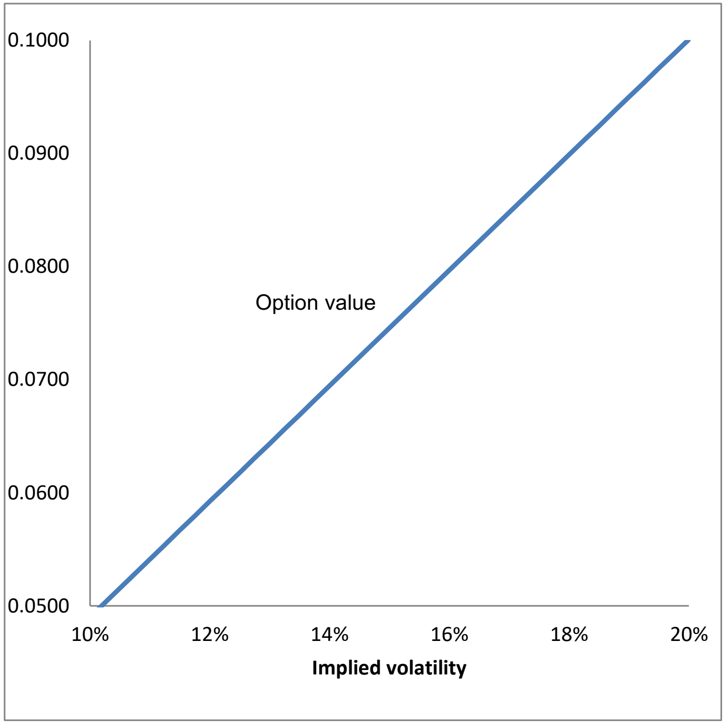
Vega as spot prices change



Vega for an ATM option as implied volatility changes

- For at-the-money options:
  - The option's value is fairly close to linear in implied volatility
  - So vega would be constant across levels of implied volatility
- But this is not true away from ATM!

Sensitivity of option price to volatility
For an at-the-money option



Vanna and GoV

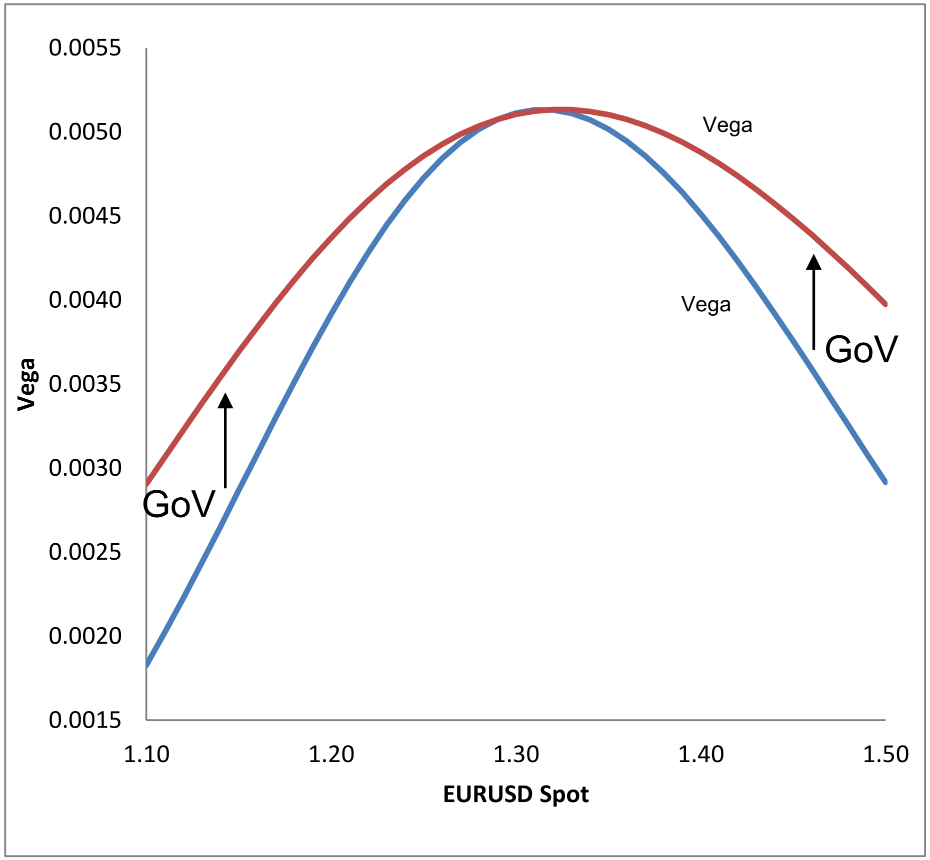
Volga (GoV)

- Volga $\partial^2 P / \partial \sigma^2$
- Sometimes called “GoV” for “Gamma of vega”
  - **W** = $\partial^2 \boldsymbol{BI} / \partial \sigma^2 = P^f S \Phi'(d_1)\, d_1\, d_2 \sqrt{(T-t)} / \sigma$

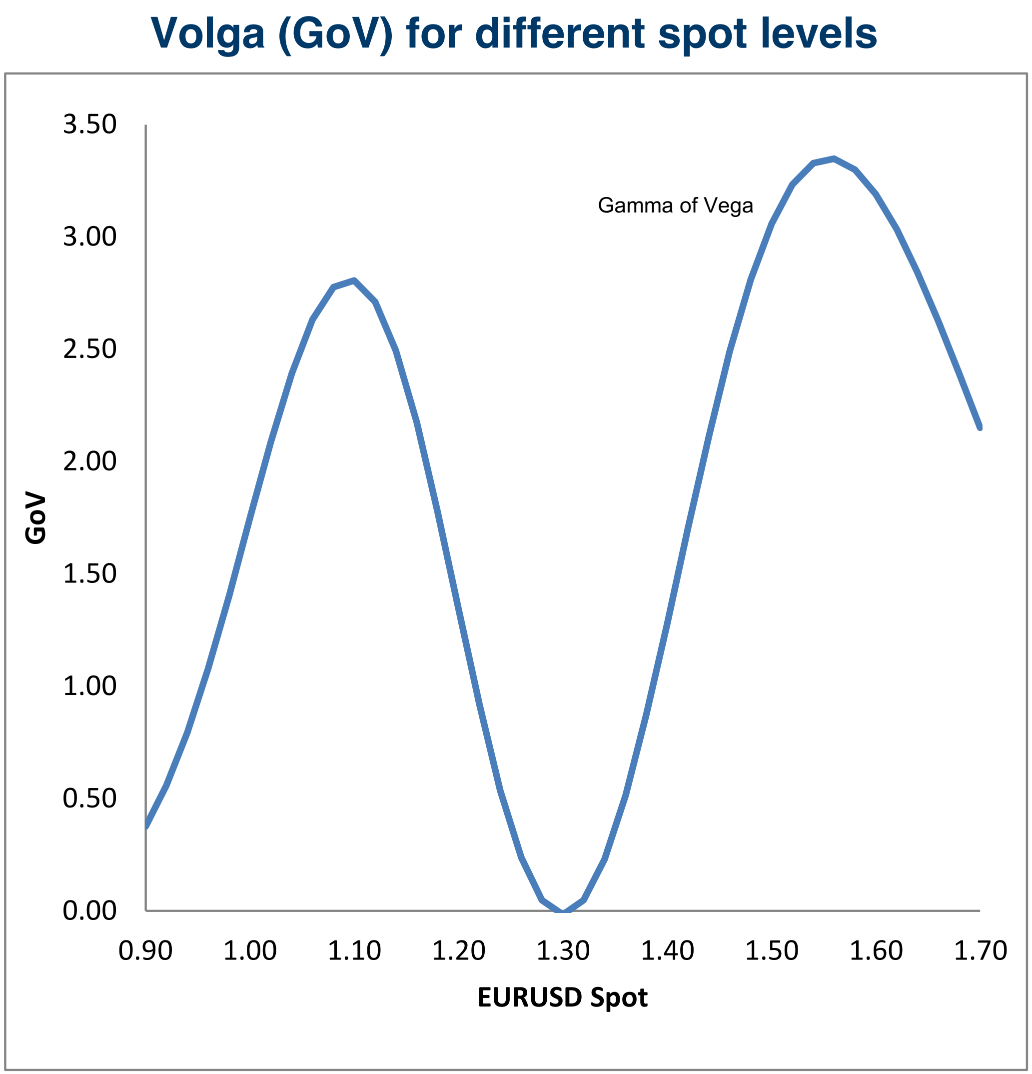
Volga: the gamma of vega ("GoV")

- How much does the vega of an option change as implied volatility changes?
  - Theoretical: $\partial^2 P / \partial\sigma^2$ Practitioner: $\Delta^2 P / \Delta\sigma^2$

Vega as spot prices change, for two volatilities



Volga: the gamma of vega ("GoV")



Rho

Rho

- How do changes in forward points impact an option's value?
  - Very similar concept as risk to interest rate differentials
- The domestic interest rate will also impact discounting
  - Discount rate risk usually ignored in short-dated options (hedge the points)
  - For longer-dated options, each interest rate will be hedged separately

Market standard practices for quoting options

Retrieving implied volatility (in the Black-Scholes model)

- All market parameters used for option pricing under Black-Scholes are generally observable -- except for volatility
  - The option contracts terms: call/put, expiry date, delivery date, strike
  - Underlying market: spot rate, foreign and domestic deposit rates
- With these parameters fixed, the Black-Scholes formula becomes a map from volatility to price
- Given an option price, we can invert the Black-Scholes formula (by numerical methods) to obtain “implied volatility”

Retrieving the strike price (in the Black-Scholes model)

- The Black-Scholes formula for an option's delta also provides a map between delta and strike
- If we are given implied volatility and all market parameters and contract terms except for strike
  - then for a specified value of delta the Black-Scholes formula can be inverted directly to produce an implied strike

Market standard practices for quoting options

- In general any date, amount and strike can be quoted
- In the professional market, among FX dealing banks and active option traders:
  - Standard dates (e.g., 1M, 3M, 1Y)
  - Standard deltas (ATM, 25D, 10D)

- Implied volatility instead of premium
  - Exact strike rate is determined by spot reference, delta and implied volatility
  - Spot "reference rate" will be set <u>after</u> implied volatility "price" is agreed

- The Black-Scholes formula is used as a standard market reference
  - This does not imply that a trading desk's actual pricing or hedging is done using the Black-Scholes model!

Example

- *Price request from an options trader:*
  - 3M EUR call USD put 25 delta, in 30
- *Response from a market-making counterparty:*
  - > 7.5 7.7
- *Trader's reply:*
  - 7.7, spot ref 1.4575
  - *Meaning that the trader buys the option at 7.70% implied volatility*

Example (continued)

- 3M EUR call USD put 25 delta, in 30
  - 7.7, spot ref 1.4575
  - *Meaning that the trader buys the option at 7.70% implied volatility*
- Exact strike rate determined by Black-Scholes formula
  - With spot = 1.4575, volatility = 7.7%, and delta = 0.25
  - Exact premium also determined by the Black-Scholes formula
- Delta hedge will be exchanged
  - EUR 7.5m versus USD 10.93m spot trade

The volatility surface

Implied and realized volatility

- Note that in practice implied volatility can vary significantly from the recently observed volatility of the underlying spot rate

1) G10
11) All G10
12) US
13) Euro
14) Japan
15) UK
16) Canada
17) Australia
18) N. Zealand
19) Switzerland
20) Denmark
21) Norway
22) Sweden

90) FX Markets Overview | 91) FX Forwards | 92) FX Options and Volatility | 93) Economics

30) Volatility Continuum - Real Vol (R) to Future Implied Vol (I) | OVDV »

	1W (Impl)	1W (Real)	1M (I)	1M (R)	3M (I)	3M (R)
EURUSD	8.53	7.66	7.68	7.82	9.99	9.50
USDJPY	17.36	10.19	11.58	8.98	11.30	11.15
GBPUSD	9.73	8.70	9.56	9.30	14.83	10.10
USDCAD	11.43	12.77	10.20	10.82	10.64	11.15
AUDUSD	12.23	12.28	11.72	12.19	12.41	12.78
NZDUSD	16.59	12.11	13.06	12.43	13.47	13.96
USDCHF	8.20	7.19	7.44	7.52	9.64	9.36
USDDKK	8.80	7.75	8.16	7.86	10.36	9.51
USDNOK	9.74	12.38	9.75	11.12	11.39	11.39
USDSEK	9.13	9.61	8.24	8.78	9.89	9.85

Implied Distributions

Breeden-Litzenberger Analysis

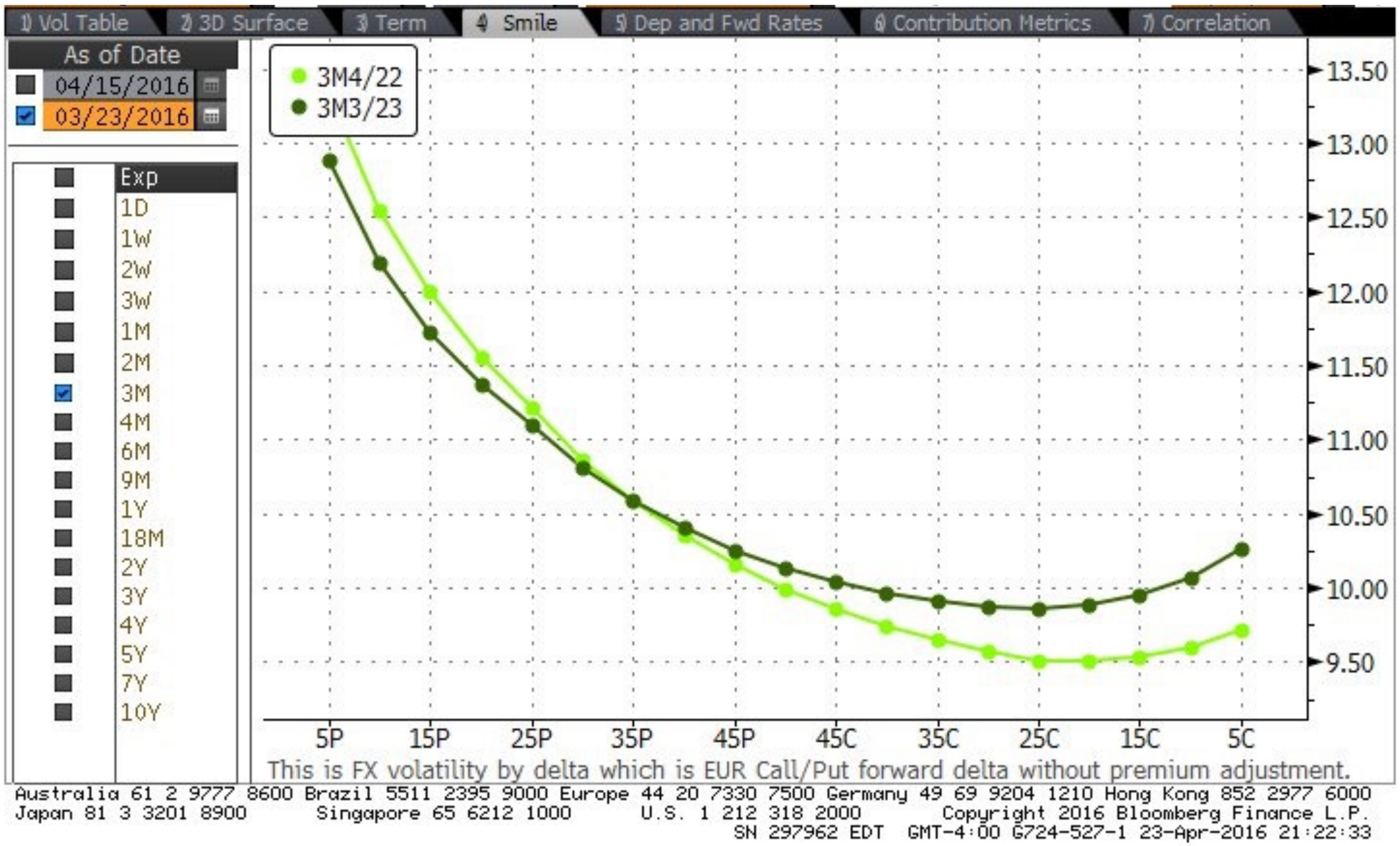
- For a fixed maturity date, T
  - A continuum of call prices across strikes, K, is equivalent to
  - An implied distribution (under the risk-neutral density) for the underlying spot rate, S
- Call price C(K) = P^d * E^Q[max(0, S_T - K)]
- With some additional derivation we can see that

$$\frac{\partial}{\partial K}\int_K^\infty (s-K) f^Q(s)ds = -\int_K^\infty f^Q(s)ds$$

- Differentiating a second time leads to the Breeden-Litzenberger formula

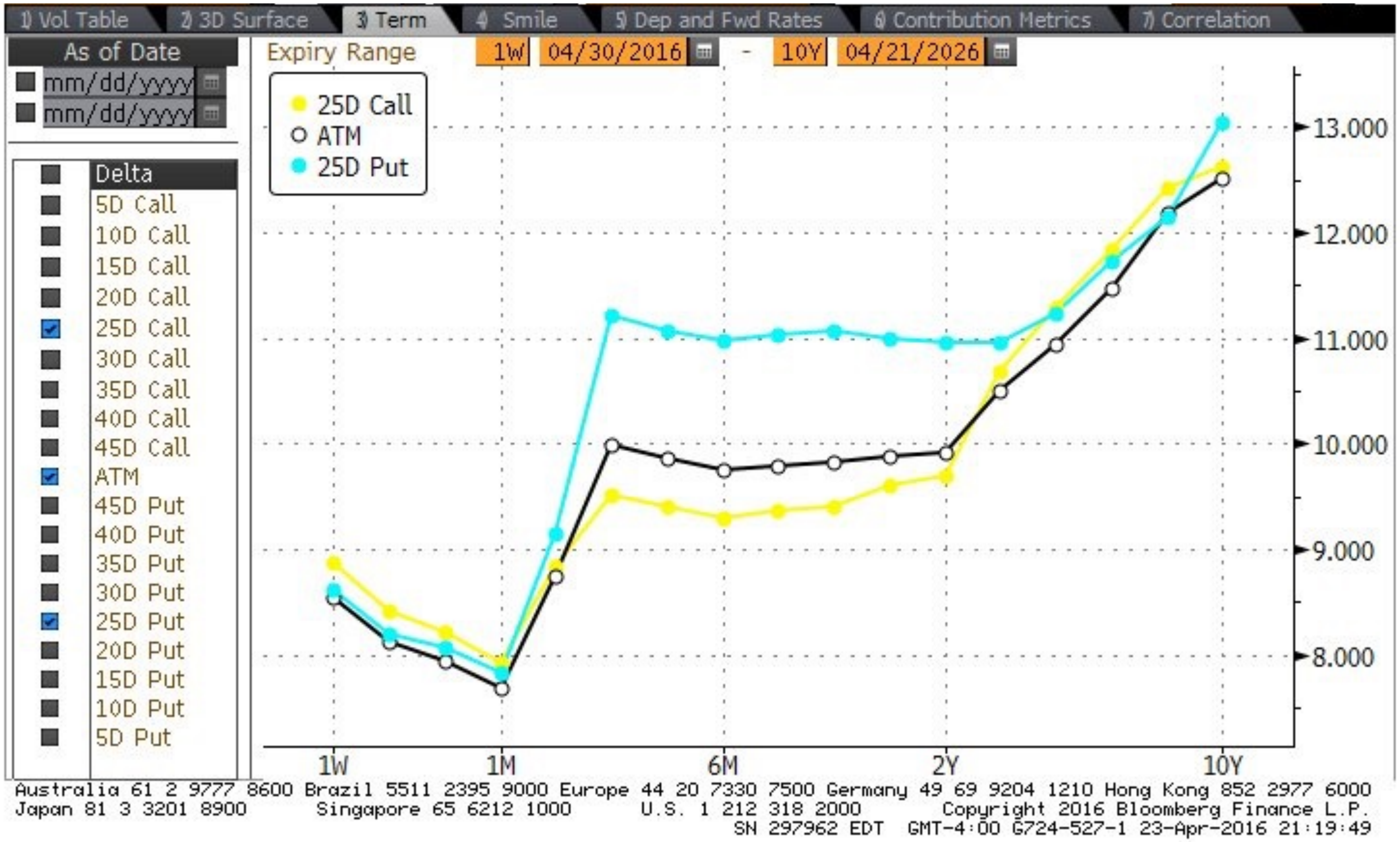
$$f^Q(K) = P^d * \frac{\partial^2}{\partial K^2} C(K)$$

Implied volatility smile – with change over one month's time



Implied volatility by option tenor

Implied volatility by option tenor – for varying strikes/deltas



Implied volatility surface

1) Vol Table | 2) 3D Surface | 3) Term | 4) Smile | 5) Dep and Fwd Rates | 6) Contribution

Format RR/BF Put/Call Side Bid/Ask Mid/Spread

	ATM	25D Call EUR	25D Put EUR	10D Call EUR	10D Put EUR
Exp	Bid / Ask	Bid / Ask	Bid / Ask	Bid / Ask	Bid / Ask
1D	3.630 / 6.340	3.467 / 6.950	3.256 / 6.746	2.179 / 8.946	1.783 / 8.592
1W	8.050 / 9.020	8.265 / 9.485	8.010 / 9.230	8.285 / 10.502	7.852 / 10.070
2W	7.785 / 8.455	8.002 / 8.843	7.782 / 8.623	8.100 / 9.628	7.742 / 9.270
3W	7.690 / 8.205	7.889 / 8.536	7.749 / 8.396	8.070 / 9.243	7.797 / 8.970
1M	7.495 / 7.870	7.689 / 8.161	7.594 / 8.066	7.938 / 8.792	7.713 / 8.567
2M	8.555 / 8.950	8.588 / 9.084	8.891 / 9.387	8.740 / 9.640	9.245 / 10.145
3M	9.765 / 10.215	9.227 / 9.793	10.932 / 11.498	9.090 / 10.115	12.030 / 13.055
6M	9.555 / 9.930	9.062 / 9.533	10.742 / 11.213	9.075 / 9.930	12.005 / 12.860
1Y	9.670 / 9.970	9.222 / 9.598	10.882 / 11.258	9.359 / 10.041	12.249 / 12.931
18M	9.725 / 10.050	9.392 / 9.800	10.795 / 11.203	9.573 / 10.312	12.133 / 12.872
2Y	9.745 / 10.095	9.469 / 9.908	10.737 / 11.176	9.704 / 10.501	12.000 / 12.795
3Y	10.175 / 10.810	10.288 / 11.085	10.565 / 11.362	10.693 / 12.139	11.236 / 12.681
5Y	11.130 / 11.800	11.424 / 12.266	11.299 / 12.141	11.930 / 13.455	11.770 / 13.295
7Y	11.940 / 12.440	12.114 / 12.741	11.839 / 12.466	11.996 / 13.134	11.496 / 12.634
10Y	12.190 / 12.840	12.212 / 13.028	12.637 / 13.453	11.788 / 13.267	12.563 / 14.042

Straddle, risk reversal, butterfly (ATM, RR, BF)

Frequently traded FX option structures

- Three frequently traded option combinations
- Used by option traders to manage risk
  - Straddle “***STDL***”

    +1 Call +1 Put, at-the-money (either delta-neutral or or forward, depending on the currency pair)

  - Risk reversal “***RR***”

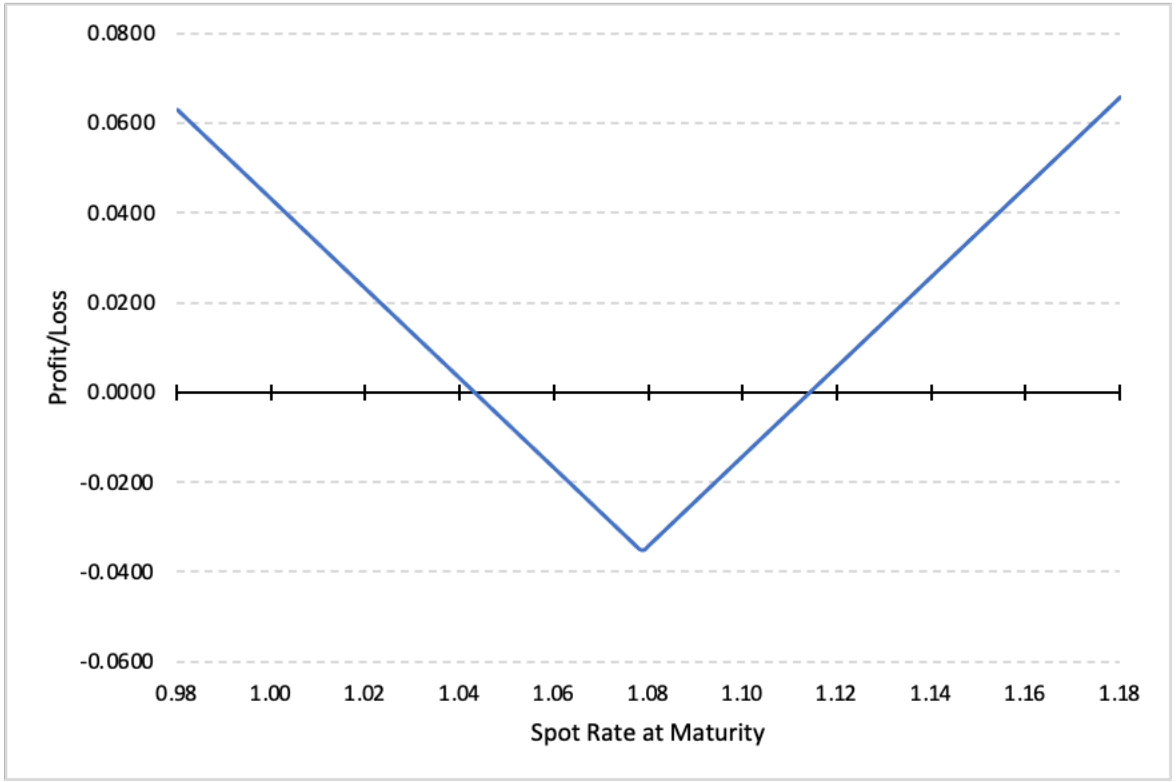
    +1 Call -1 Put, 25 delta

  - Butterfly “***VWB***”

    +1 Call +1 Put (STDL) and -1 Call -1 Put, 25 delta, “vega-weighted”

Straddles

- Straddle "***STDL***" : *+1 Call +1 Put, at-the-money*



Straddles

- "At-the-money straddle", buy a base currency call and a base currency put "at the money". Depending on the currency pair, this can be either the "delta-neutral strike" ***(DNS)****, or* "at the forward rate" ***(ATMF)***

Example

  - 1M EURUSD [straddle] in 50 *(price request from an options trader)*
  - > 8.1 8.3 *(response from a market-making counterparty)*
  - 8.3, spot ref 1.4575 *(trader buys the straddle at 8.30% implied volatility)*
  - Note, the trader will buy both a 25m EUR call and 25m EUR put at a strike calculated so that the call and put have equal deltas (of opposite signs)
  - No delta hedge will be exchanged between the counterparties

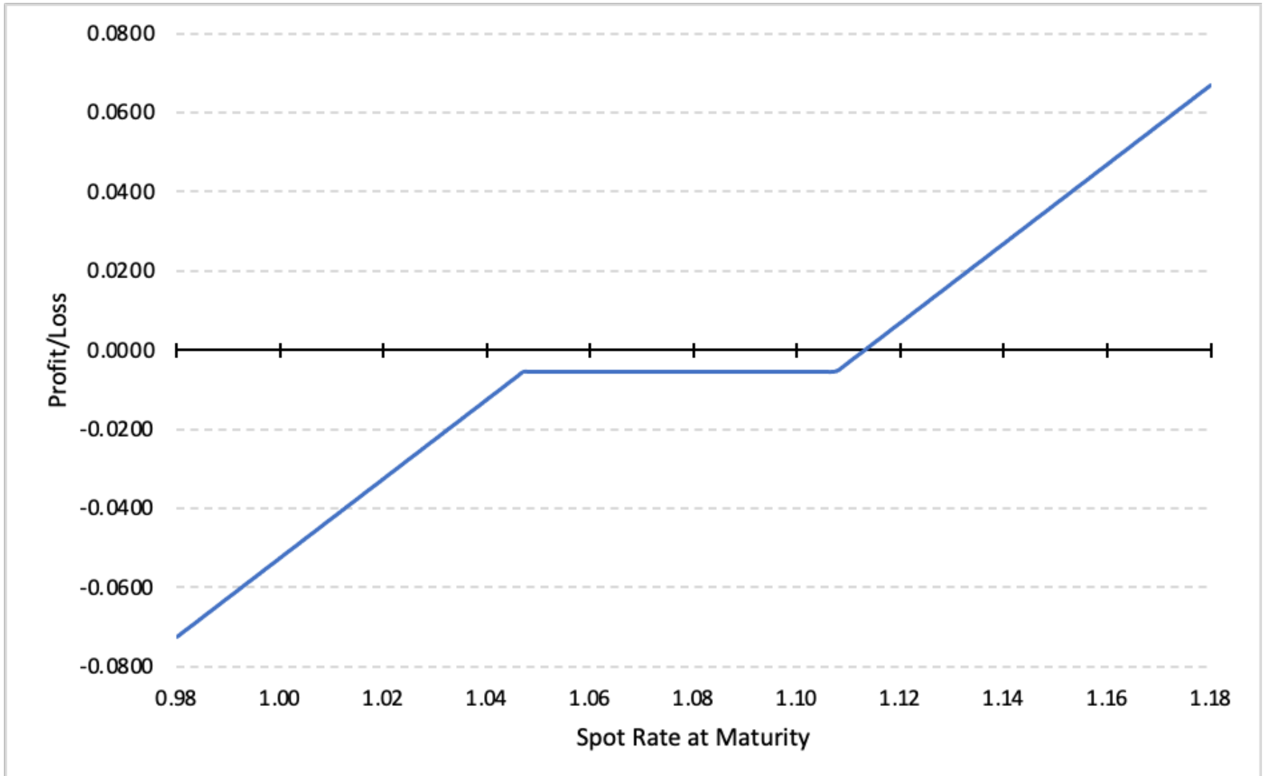
Straddles

- Market convention for the currency pair will determine whether DNS or ATMF applies
  - Often emerging market currency traders will prefer ATMF straddles, otherwise DNS

- Note that delta is calculated using Black-Scholes
  - A DNS straddle may have a non-zero delta under less simple pricing assumptions

Risk Reversals

- Risk reversal "***RR***" : *+1 Call -1 Put, 25 delta*



Risk Reversals

- “Risk reversal”, buy a base currency call and sell a put, typically 25 delta (of opposite signs)
- “Risk reversal” will also denote the difference in implied volatility between a 25 delta call and put
    - Sometimes negative numbers indicate puts have higher implied volatility
    - Sometimes traders will assume this direction is known (or will specify “puts”)

Risk Reversals – Example

USDJPY 6M 25d RR in 100 *(price request from an options trader)*

> 1.7 1.8 puts *(response from a market-making counterparty)*

OR, > -1.8 -1.7 *(negative specifies that puts have higher implied volatility)*

OR, > 1.7 1.8 *(assuming that both trader and market-maker know puts are "preferred")*

> 1.7, spot ref 108.35 *(trader sells the risk reversal, with puts preferred, at a 1.70% implied volatility spread)*

> vols 11.85 10.15 *(market-maker indicates implied volatility for the put and call, in that order since puts are preferred. Here ATM volatility is assumed to be 11.00% because half the 1.70% risk reversal spread will be added/subtracted to the ATM volatility to determine the put/call implied volatility)*

Risk Reversals – Example (continued)

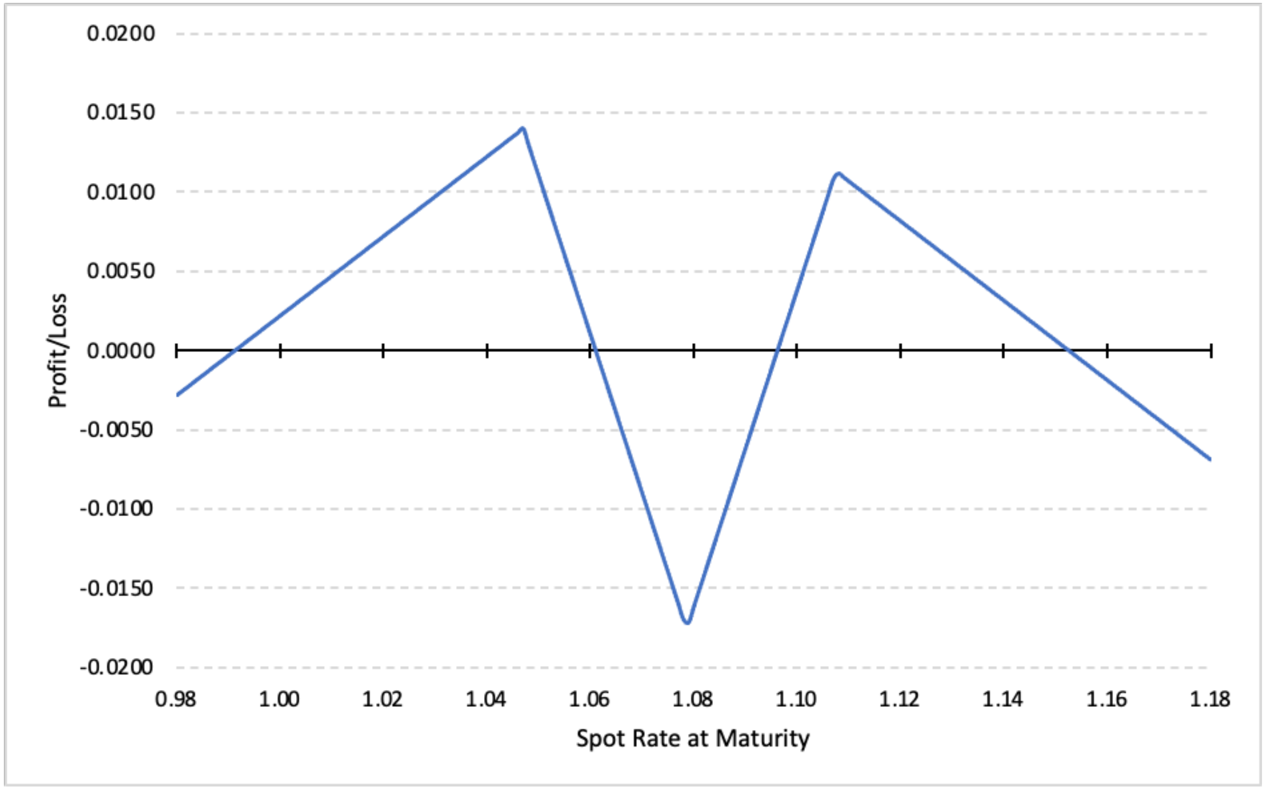
USDJPY 6M 25d RR in 100 *(price request from an options trader)*

> > 1.7, spot ref 108.35 *(trader sells the risk reversal, with puts preferred, at a 1.70% implied volatility spread)*
>
> > vols 11.85 10.15 *(market-maker indicates implied volatility for the put and call, in that order since puts are preferred. Here ATM volatility is assumed to be 11.00% because half the 1.70% risk reversal spread will be added/subtracted to the ATM volatility to determine the put/call implied volatility)*

- Note, the trader will buy 100m of the USD call at 10.15% implied volatility and sell 100m of the USD put at 11.85% implied volatility
- Delta will be exchanged, the trader will sell 50m USD at the reference rate 108.35

Butterfly

- Butterfly "***VWB***" : *+1 STDL and -1 Call -1 Put, 25 delta, "vega-weighted"*



Butterfly

- "Butterfly", buy a call and put (a "strangle"), typically 25 delta, and sell an at-the-money straddle
- "Fly" or "BF" will also denote the difference in implied volatility between
  - Average of [25 delta] call and put (a.k.a., "the wings") - At-the-money volatility
  - Typically a positive number. *<u>Negative</u>* quote always means the "wings" are *<u>lower</u>*
  - The traded structure is usually "vega weighted": the strangle notional will be larger than the straddle notional, with proportions to create equal and offsetting vega (sensitivity to volatility)

Butterfly – Example

EURJPY 1y 25d fly in 250 *(price request from trader, 250m EUR per leg of straddle)*

> 0.275 0.375 *(response from a market-making counterparty)*

0.375, spot ref 158.25 *(trader buys the butterfly, buying the strangle and selling the straddle, with implied volatility for the strangle 0.375% higher than implied volatility for the straddle)*

> vol for ATM 10.90 *(market-maker indicates implied volatility of 10.90% for the straddle)*

Butterfly – Example (continued)

EURJPY 1y 25d fly in 250

0.375, spot ref 158.25

> vol for ATM 10.90

- Note, the trader will:
  - sell 250m per leg of the ATM (typically DNS) straddle at 10.90% implied volatility, and
  - buy a 25 delta call and 25 delta put both at 11.275% implied volatility
- The notional will be increased to make the entire transaction vega neutral (under the Black-Scholes model with the specified implied volatilities)
- Assumed to be both delta-neutral and vega-neutral for dealing purposes

Implied volatility surface – with RR and BF

1) Vol Table | 2) 3D Surface | 3) Term | 4) Smile | 5) Dep and Fwd Rates | 6) Contribution

Format: RR/BF Put/Call Side: Bid/Ask Mid/Spread

	ATM	25D RR	25D BF	10D RR	10D BF
Exp	Bid / Ask	Bid / Ask	Bid / Ask	Bid / Ask	Bid / Ask
1D	3.630 / 6.340	-0.740 / 1.155	-0.555 / 0.795	-1.250 / 2.000	-0.695 / 1.475
1W	8.050 / 9.020	-0.085 / 0.595	-0.030 / 0.455	-0.150 / 1.015	0.255 / 1.030
2W	7.785 / 8.455	-0.015 / 0.455	0.025 / 0.360	-0.045 / 0.760	0.295 / 0.835
3W	7.690 / 8.205	-0.040 / 0.320	0.065 / 0.325	-0.040 / 0.585	0.365 / 0.780
1M	7.495 / 7.870	-0.035 / 0.225	0.100 / 0.290	0.000 / 0.450	0.420 / 0.720
2M	8.555 / 8.950	-0.440 / -0.165	0.135 / 0.335	-0.740 / -0.270	0.530 / 0.850
3M	9.765 / 10.215	-1.860 / -1.550	0.260 / 0.485	-3.210 / -2.670	0.905 / 1.260
6M	9.555 / 9.930	-1.810 / -1.550	0.300 / 0.490	-3.155 / -2.705	1.075 / 1.375
1Y	9.670 / 9.970	-1.765 / -1.555	0.345 / 0.495	-3.070 / -2.710	1.205 / 1.445
18M	9.725 / 10.050	-1.515 / -1.290	0.330 / 0.490	-2.755 / -2.365	1.205 / 1.465
2Y	9.745 / 10.095	-1.390 / -1.145	0.315 / 0.490	-2.505 / -2.085	1.190 / 1.470
3Y	10.175 / 10.810	-0.500 / -0.055	0.175 / 0.490	-0.925 / -0.160	0.940 / 1.450
5Y	11.130 / 11.800	-0.110 / 0.360	0.150 / 0.485	-0.245 / 0.565	0.880 / 1.415
7Y	11.940 / 12.440	0.100 / 0.450	-0.025 / 0.225	0.200 / 0.800	-0.075 / 0.325
10Y	12.190 / 12.840	-0.650 / -0.200	0.155 / 0.480	-1.165 / -0.385	0.140 / 0.660