

# MENTAL MODELS FOR VOLATILITY

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# GOAL: INTUITION FOR VOLATILITY

- Where it comes from
- Common applications
- Real-world example

## Baseline vs. Progressive



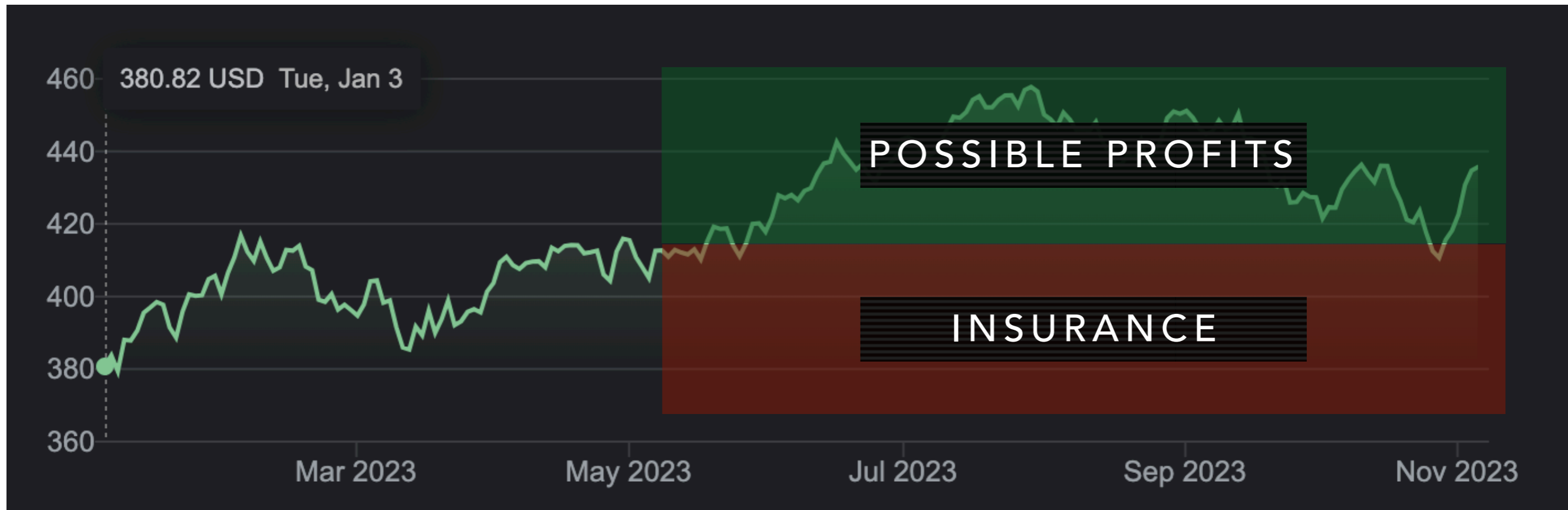
WHAT WILL WE REMEMBER?

**IDEA #1**

**BLACK-SCHOLES MODEL**

# OPTIONS

- Right to buy or sell at a given price, for some time



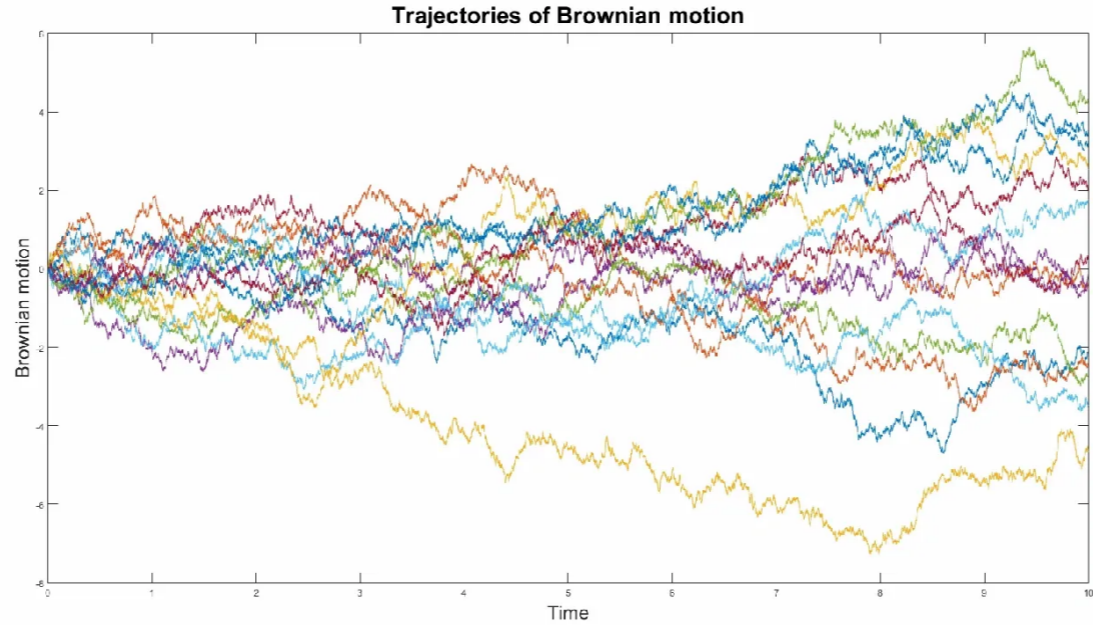
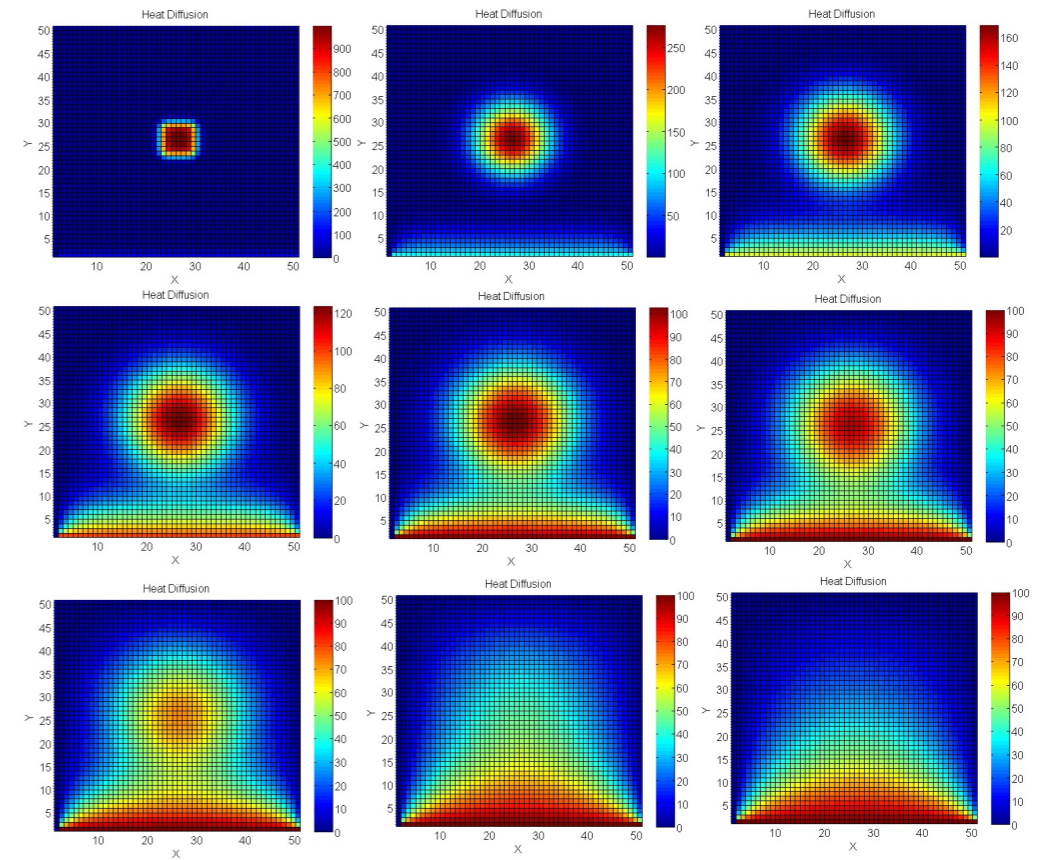
- Everyday examples: Pre-orders, coupons, insurance, warranty...

# WHAT SHOULD OPTIONS COST?

- Historically: contracts traded individually, over the counter
- How much should you pay? Which factors matter?
- Pricing car insurance based on:

VARIABLE	Sensitivity of value
CAR AGE	?
CAR VALUE	?
YOUR AGE	?
YOUR RISK FACTORS	?
POLICY COVERAGE	?

	May																															Jun						
SPY	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	Exp	+/-%							
500.00	2344	2345	2347	2349	2350	2351	2353	2354	2355	2356	2356	2357	2358	2358	2358	2359	2359	2359	2359	2360	2360	2360	2360	2360	2360	2360	2360	2361	2361	2361	2361	2361	21.81%					
495.00	2337	2339	2341	2344	2346	2348	2349	2351	2352	2354	2355	2356	2357	2357	2358	2358	2359	2359	2359	2360	2360	2360	2360	2360	2360	2360	2361	2361	2361	2361	2361	2361	20.59%					
490.00	2327	2330	2333	2336	2339	2342	2344	2346	2348	2350	2352	2353	2355	2356	2357	2358	2358	2359	2359	2359	2360	2360	2360	2360	2360	2361	2361	2361	2361	2361	2361	19.37%						
485.00	2312	2317	2321	2325	2329	2332	2336	2339	2342	2345	2347	2350	2352	2353	2355	2356	2357	2358	2359	2359	2360	2360	2360	2360	2360	2361	2361	2361	2361	2361	2361	18.15%						
480.00	2292	2298	2303	2309	2314	2319	2323	2328	2332	2336	2339	2343	2346	2349	2351	2353	2355	2356	2358	2359	2359	2360	2360	2360	2360	2361	2361	2361	2361	2361	2361	16.93%						
475.00	2264	2272	2279	2285	2292	2299	2305	2311	2317	2322	2327	2332	2336	2341	2344	2348	2351	2353	2355	2357	2358	2359	2360	2360	2360	2361	2361	2361	2361	2361	2361	15.72%						
470.00	2227	2236	2244	2253	2261	2270	2278	2286	2293	2301	2308	2315	2321	2327	2333	2338	2343	2347	2351	2354	2356	2358	2359	2360	2360	2361	2361	2361	2361	2361	2361	14.50%						
465.00	2176	2187	2198	2209	2219	2230	2240	2250	2260	2270	2279	2288	2297	2306	2314	2321	2329	2335	2341	2346	2351	2354	2357	2359	2360	2360	2361	2361	2361	2361	2361	13.28%						
460.00	2110	2123	2136	2149	2162	2174	2187	2200	2212	2225	2237	2249	2261	2272	2283	2294	2305	2315	2324	2332	2340	2346	2352	2356	2359	2360	2360	2361	2361	2361	2361	12.06%						
455.00	2026	2041	2056	2071	2086	2101	2116	2131	2146	2161	2177	2192	2207	2222	2237	2251	2266	2280	2293	2306	2318	2330	2339	2348	2354	2358	2360	2361	2361	2361	2361	10.84%						
450.00	1919	1936	1953	1970	1987	2004	2022	2040	2057	2076	2094	2112	2131	2149	2168	2187	2205	2224	2243	2261	2279	2297	2313	2328	2341	2352	2358	2361	2361	2361	9.63%							
445.00	1786	1805	1823	1842	1861	1881	1901	1921	1941	1962	1983	2004	2026	2048	2070	2093	2116	2140	2164	2188	2213	2237	2262	2286	2310	2331	2349	2359	2361	2361	8.41%							
440.00	1625	1645	1665	1685	1706	1727	1748	1770	1792	1815	1838	1862	1887	1911	1937	1963	1990	2018	2047	2077	2107	2139	2172	2207	2242	2279	2315	2347	2361	2361	7.19%							
435.00	1433	1453	1474	1495	1517	1539	1561	1584	1608	1632	1656	1682	1708	1735	1762	1791	1820	1851	1883	1917	1952	1989	2028	2071	2117	2167	2223	2288	2356	2361	5.97%							
430.00	1207	1227	1248	1270	1292	1314	1337	1360	1384	1408	1433	1459	1486	1513	1541	1570	1601	1633	1666	1700	1737	1776	1818	1863	1913	1969	2034	2117	2248	2361	4.75%							
425.00	946	967	987	1008	1029	1051	1073	1096	1119	1143	1167	1192	1218	1245	1272	1300	1329	1360	1391	1424	1459	1496	1535	1576	1622	1671	1727	1790	1857	1861	3.53%							
420.00	651	671	690	710	730	750	771	793	814	836	859	882	906	930	955	980	1006	1033	1061	1090	1120	1151	1182	1216	1250	1284	1319	1349	1361	1361	2.32%							
415.00	323	341	358	377	395	413	432	451	471	490	510	530	551	572	593	615	637	659	682	704	727	750	773	795	817	836	851	860	861	861	1.10%							
410.00	-37	-21	-6	10	26	42	59	75	92	108	125	142	159	176	193	210	227	244	261	277	293	308	322	335	346	355	359	361	361	361	-0.12%							
405.00	-426	-412	-399	-385	-372	-358	-345	-332	-318	-305	-291	-278	-265	-252	-239	-226	-214	-202	-191	-180	-170	-162	-154	-148	-143	-140	-139	-139	-139	-139	-1.34%							
400.00	-840	-829	-818	-807	-796	-785	-774	-764	-753	-743	-733	-723	-714	-704	-695	-687	-678	-671	-664	-658	-652	-648	-644	-641	-640	-639	-639	-639	-639	-639	-2.56%							
395.00	-1275	-1267	-1258	-1249	-1241	-1233	-1225	-1217	-1209	-1202	-1194	-1187	-1181	-1175	-1169	-1163	-1158	-1154	-1150	-1147	-1144	-1142	-1140	-1140	-1139	-1139	-1139	-1139	-1139	-1139	-3.77%							
390.00	-1729	-1722	-1716	-1709	-1703	-1697	-1691	-1685	-1680	-1675	-1670	-1665	-1661	-1657	-1654	-1651	-1648	-1645	-1643	-1642	-1641	-1640	-1639	-1639	-1639	-1639	-1639	-1639	-1639	-1639	-1639	-4.99%						
385.00	-2196	-2191	-2187	-2182	-2178	-2173	-2169	-2166	-2162	-2159	-2155	-2153	-2150	-2148	-2146	-2144	-2143	-2141	-2141	-2140	-2139	-2139	-2139	-2139	-2139	-2139	-2139	-2139	-2139	-2139	-2139	-6.21%						
380.00	-2674	-2671	-2667	-2664	-2661	-2658	-2656	-2653	-2651	-2649	-2647	-2646	-2644	-2643	-2642	-2641	-2640	-2640	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-2639	-7.43%						
375.00	-3160	-3157	-3155	-3153	-3151	-3150	-3148	-3146	-3145	-3144	-3143	-3142	-3141	-3141	-3140	-3140	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-3139	-8.65%						
370.00	-3651	-3649	-3648	-3647	-3645	-3644	-3643	-3643	-3642	-3641	-3641	-3640	-3640	-3640	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-3639	-9.86%						
365.00	-4145	-4145	-4144	-4143	-4142	-4142	-4141	-4141	-4140	-4140	-4140	-4140	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-4139	-11.08%						
360.00	-4642	-4642	-4641	-4641	-4641	-4640	-4640	-4640	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-4639	-12.30%						



OPTIONS VALUE ~ HEAT TRANSFER + RANDOM MOTION

# BLACK-SCHOLES MODEL

WHAT DETERMINES OPTIONS PRICE?	
VARIABLE	Sensitivity of option value ("Greeks")
STRIKE PRICE	Fixed during contract
STOCK PRICE	Delta, Gamma
VOLATILITY	Vega
INTEREST RATE	Rho
TIME LEFT	Theta

$$C(S, t) = N(d_1)S - N(d_2)Ke^{-rT}$$

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$C(S, t)$  (call option price)

$N()$  (cumulative distribution function)

$T = (T_1 - t)$  (time left til maturity (in years))

$S$  (stock price)

$K$  (strike price)

$r$  (risk free rate)

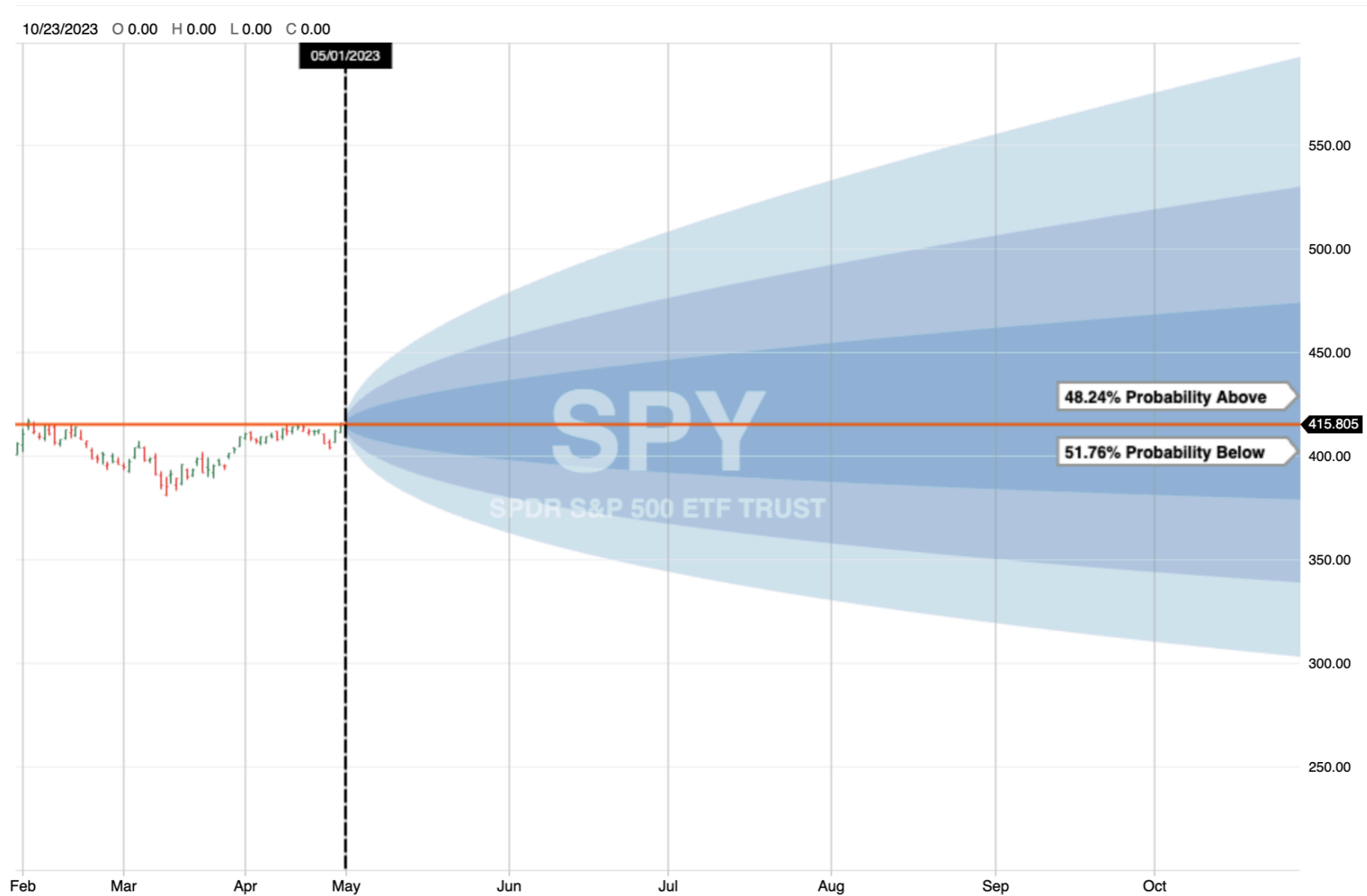
$\sigma$  (volatility)

**IDEA #2**

**ROLE OF VOLATILITY & TIME**



# WILL AN OPTION BE PROFITABLE?

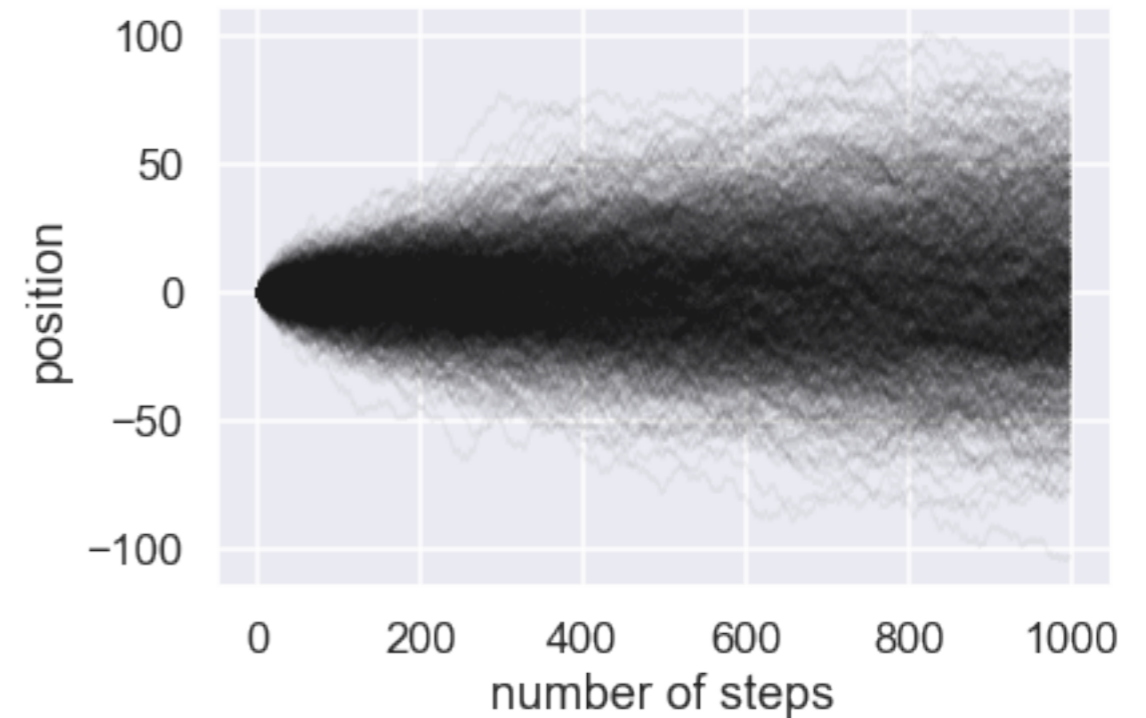


Example options calculator

(Can we build one?)

# WILL WE HIT A GIVEN PRICE?

- More vol = more likely
- More time = more likely
- Based on **Vol  $\times$   $\sqrt{\text{Time}}$**
- 4x the time, only 2x the range



# VOLATILITY AND TIME

OPTION VALUE

INTRINSIC

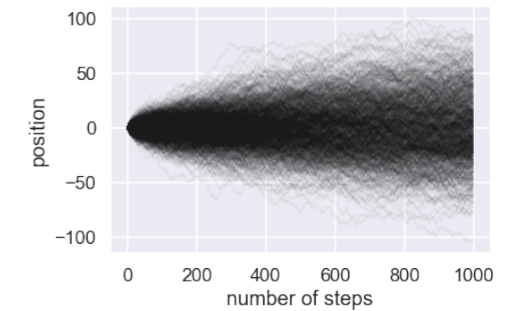
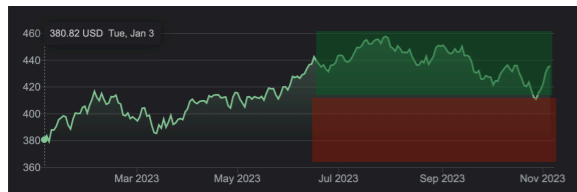
EXTRINSIC

IMMEDIATE  
VALUE

FUTURE  
POTENTIAL

STRIKE PRICE  
STOCK PRICE

VOLATILITY  
TIME



EXAMPLE: SPY @ 400

390 CALL = 10 (INTRINSIC) + FUTURE  
400 CALL = 0 (INTRINSIC) + FUTURE

**IDEA #3**

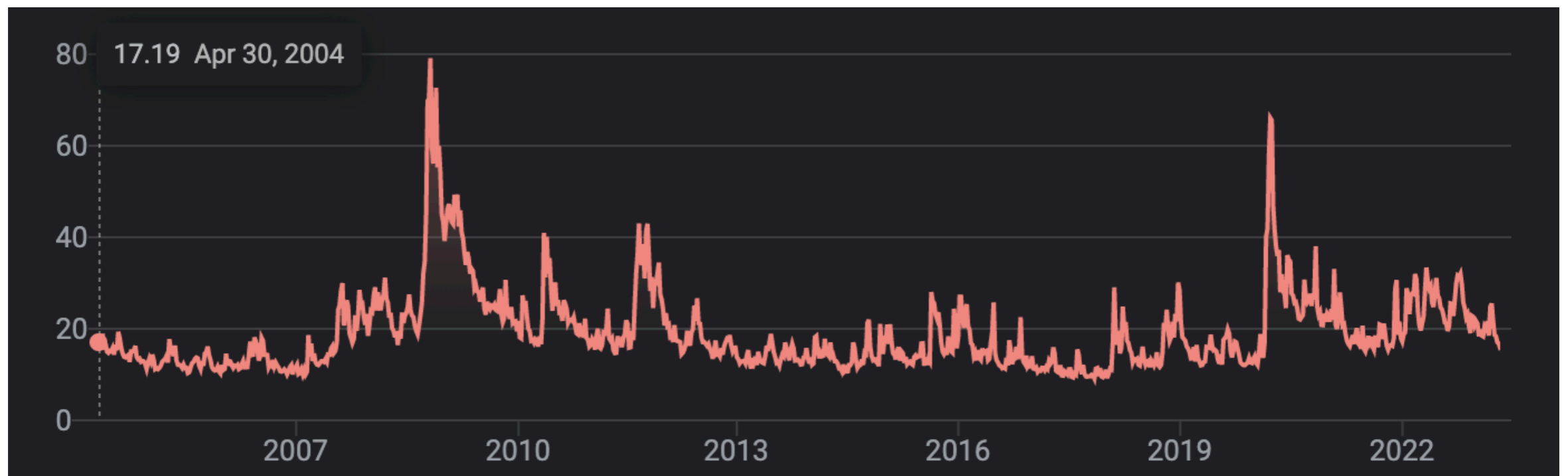
**MAKING ESTIMATES**

# PROBLEM: WHAT IS FUTURE VOL?

- Future volatility (risk) is unknown
- Solution: Based on option prices, what volatility is implied?
  - Other variables (option price, strike price, stock price, time, interest rate) are known. We can solve for the priced-in volatility.
  - Result: expected annual % change (std deviation, sigma)
  - Analogy: based on your car insurance, what's your implied risk?

# CBOE VIX INDEX (VOL INDEX)

- Tracks implied volatility (IV) on SPX options
- Expressed as annual rate (VIX 24 = 24% standard deviation)
- Estimate of market sentiment, inversely correlated("fear index")

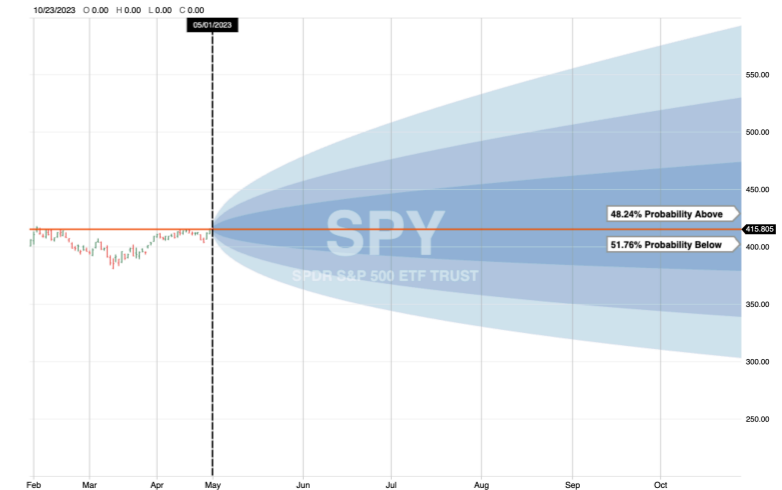


# MAKING QUICK ESTIMATES

ROAD TRIP	STOCK PRICE
SPEED	VOL (STANDARD DEVIATION)
TIME	TIME
$\text{DISTANCE} = \text{SPEED} \times \text{TIME}$	$\text{PRICE RANGE} = \text{VOL} \times \sqrt{\text{TIME}}$
EXAMPLE: 60 MPH FOR 3 HOURS = 180 MILES	EXAMPLE: TURN VOL INTO PRICE RANGE

# RULE OF 68-95-99.7

- Percent of values within a 1/2/3 sigma move
- Example using VIX = 24% (annual)



CHANCE	MOVE	RANGE (1 YEAR)	$E^{(LOW)}$ $E^{(HIGH)}$	SPY @ 450
68%	±1 SIGMA	±24%	-21.3% +27.1%	354 TO 572
95%	±2 SIGMA	±48%	-38.1% +61.6%	278 TO 727
99.7%	±3 SIGMA	±72%	-51.3% +105.4%	219 TO 924

Exponential growth:  
 $e^{(change)}$  vs  
 $(1 + change)$



# CHECKPOINT

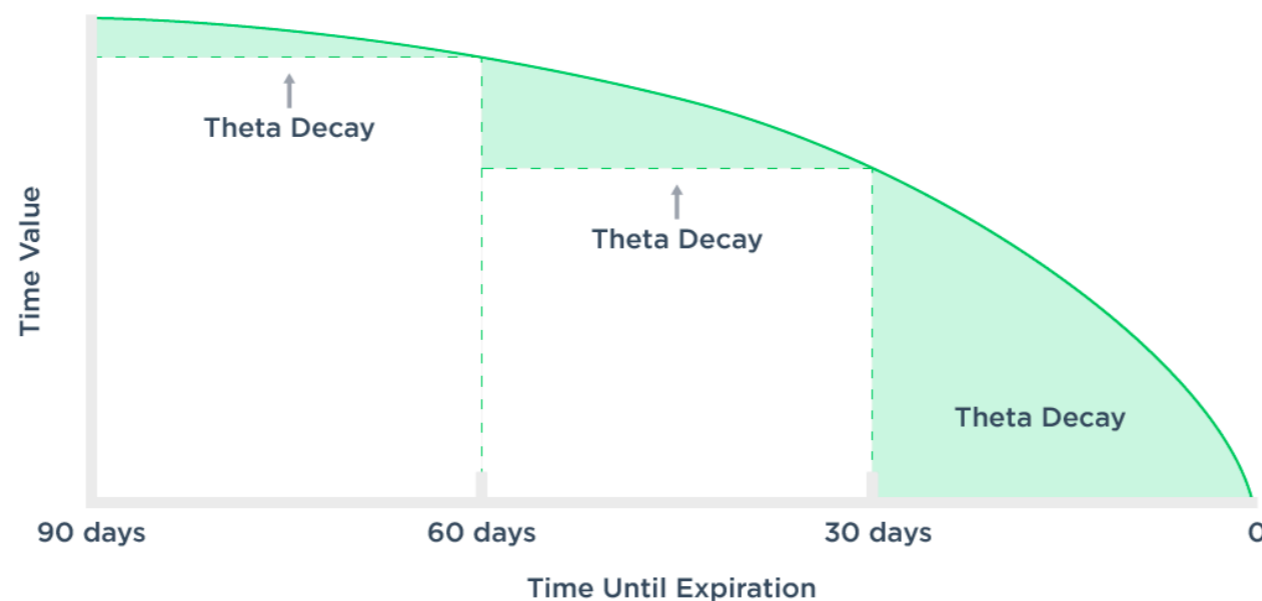
- Black-Scholes model identifies volatility as a key variable
- Options Price = Current Value + Future Potential
- Implied volatility is market's estimate for annual % change

# REAL-WORLD APPLICATIONS

# APPLICATION: DECAY CURVE

- Analogy: Ice cube melting (barely perceptible, then faster)
- Remember:  $\text{Vol} \times \sqrt{\text{Time}}$ 
  - Most decay happens closest to expiration
  - Extra time far away is cheap ("bulk discount")

Theta Decay

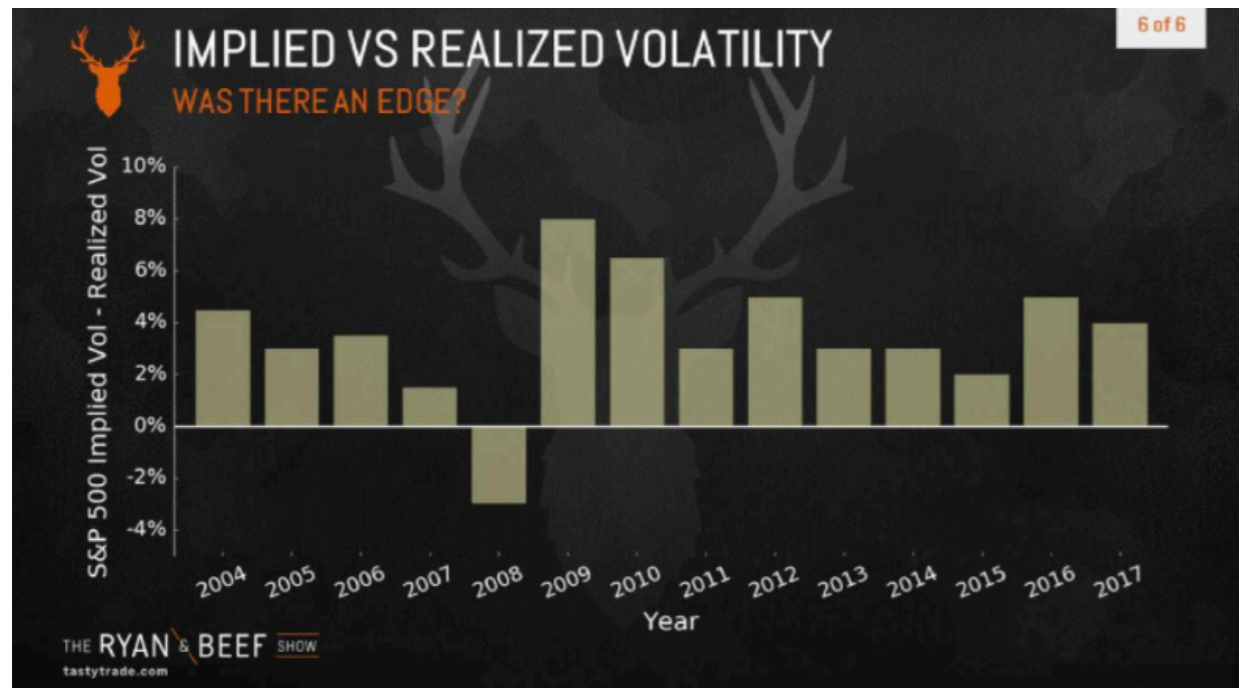


# APPLICATION: VOL DRAG

PORTFOLIO	YEAR 1	YEAR 2	YEAR 3	YEAR 4	AVG	TRUE RETURN
A	10%	10%	10%	10%	10%	$(1.10)^4$ = 46.4% GAIN
B	5%	15%	5%	15%	10%	$(1.05)^2(1.15)^2$ = 45.8% GAIN
C	0%	20%	0%	20%	10%	$(1.20)^2$ = 44% GAIN

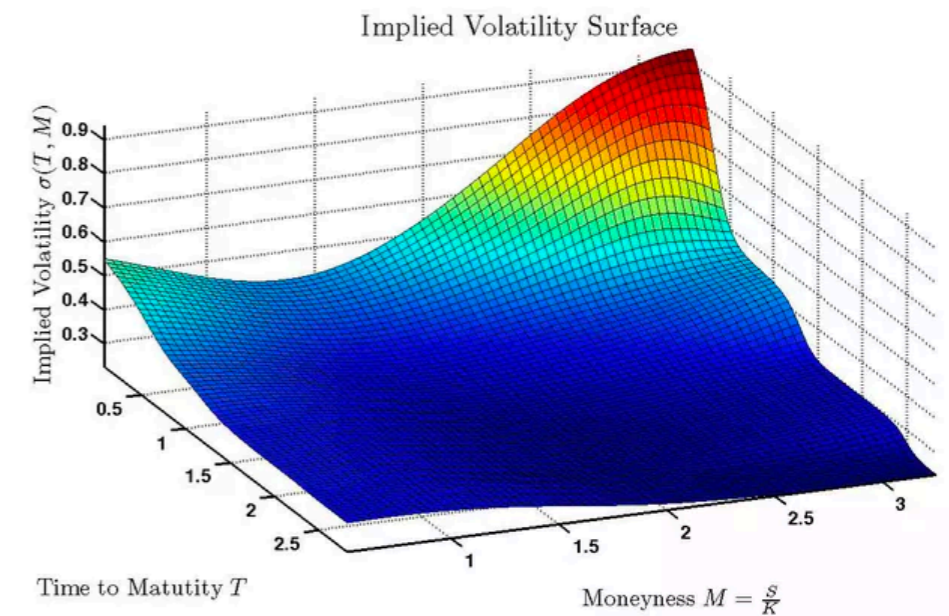
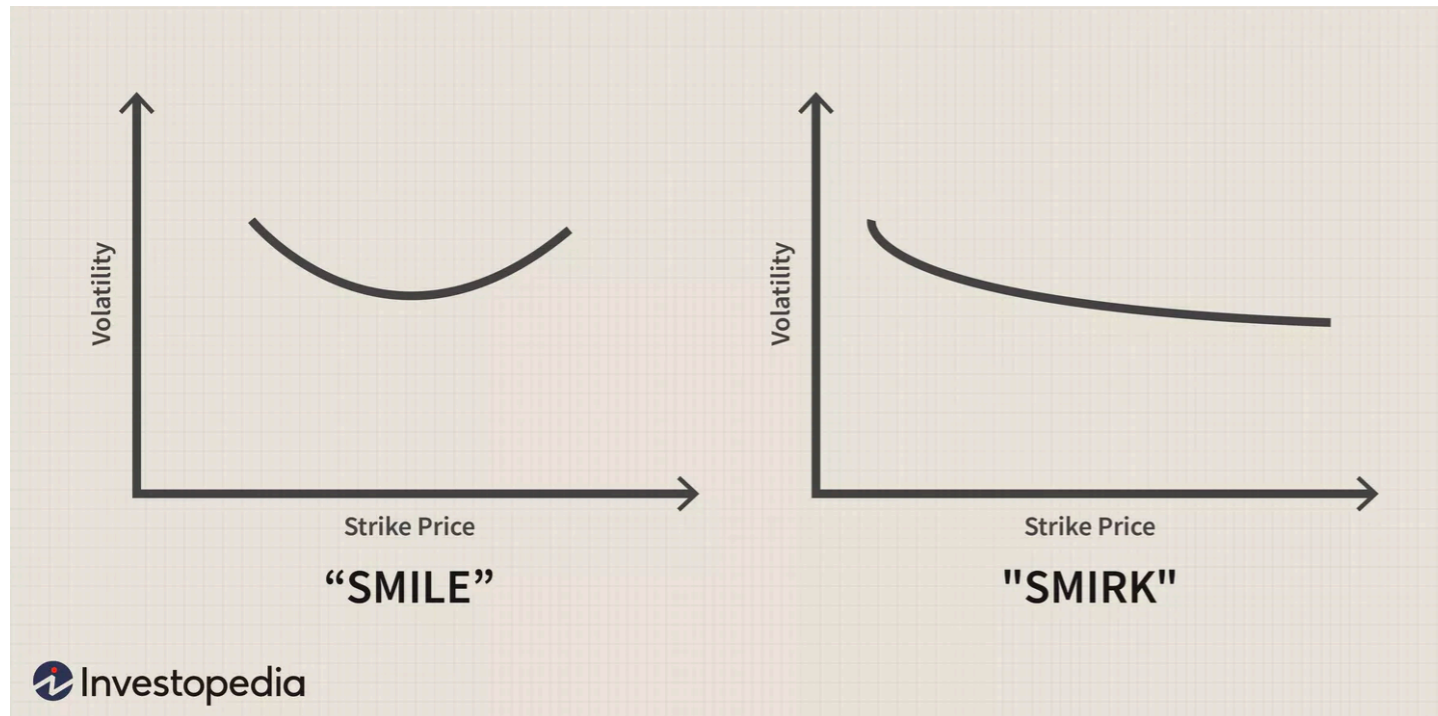
- A is best. Smoother returns = higher gain
- For identical returns, pick portfolio with less vol

# APPLICATION: REALIZED VS IMPLIED



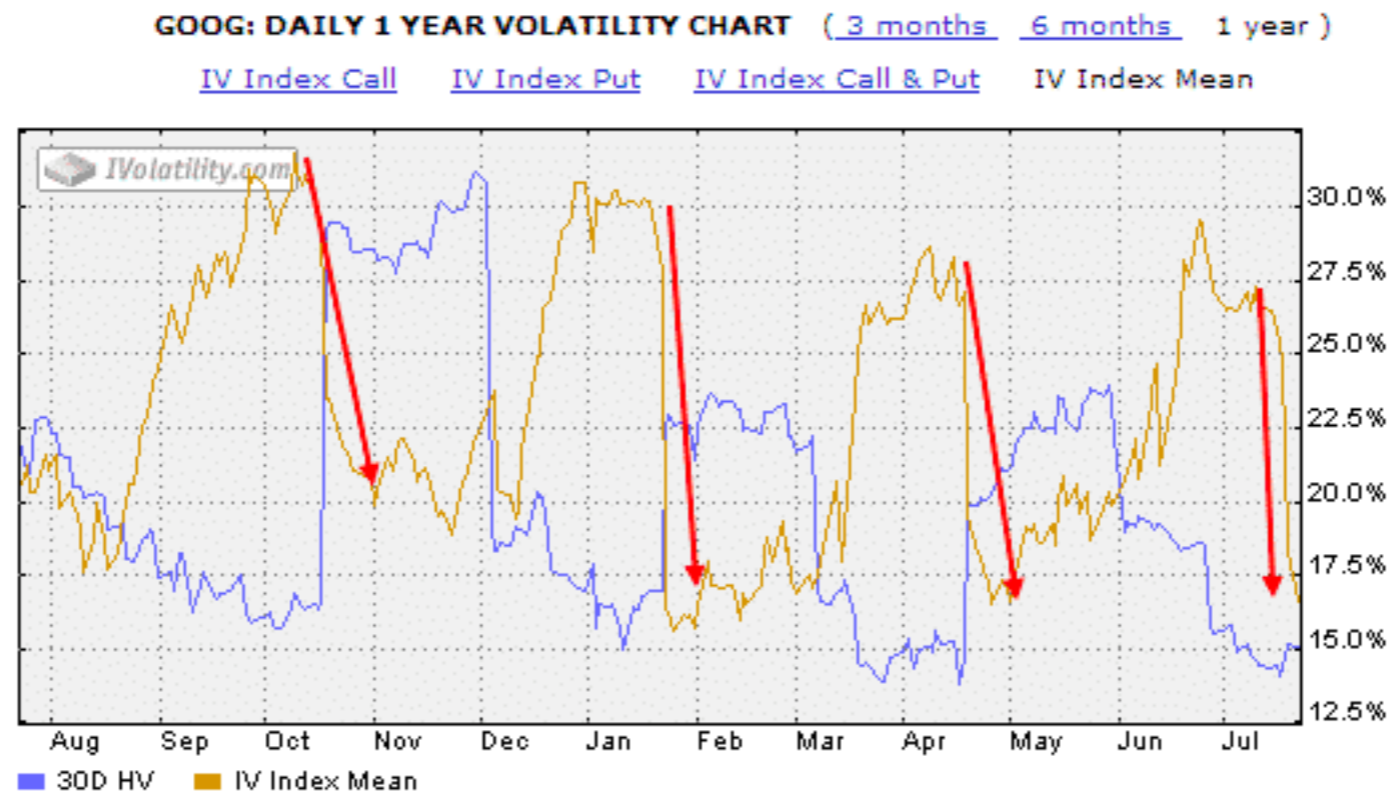
- Theory: Option premiums reflect future variability
- Practice: People buy more insurance than expected
  - Realized Vol (how market moved) < Implied Vol (risk premiums paid)
  - Analogy: Extended warranties

# APPLICATION: VOL SKEW



- Theory: All strikes & times price in same future volatility
- Practice: People pay more for downside protection
  - Risk aversion, underpriced black swan events/fat tails...

# APPLICATION: IV CRUSH



- With near-term uncertainty, premium for short-term options
  - Long-term options less impacted
- IV drops after uncertainty passes (interest rate announcement, earnings report, etc)
  - Impacts the time value portion

# **PRICING EXAMPLE**

**(ROUGH IDEAS → FINER DETAIL)**



# APPLICATION: PUT/CALL PARITY

- **Puts/Calls at same strike should have same IV (risk estimate)**
- Options, stocks and risk-free returns can synthetically model each other
  - $\text{Call} + \text{PV}(\text{Strike Price}) = \text{Put} + \text{Stock}$
  - If put/call have different risk, arbitrage: sell high IV, buy lower IV synthetic

# SCENARIO: 4/28/23 SPY @ 415.50

Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta	Action	Strike ▲	Action	Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta
				<b>CALLS</b>							<b>PUTS</b>							
				<b>May 05 '23 (7 days)</b>														
?				6,330	9,442	?	0.6719	▼	412	▼	?				23,754	7,102	?	-0.3305
				8,193	8,007		0.6533	▼	412.5	▼					5,435	6,220		-0.3494
				16,255	13,100		0.6336	▼	413	▼					15,283	11,916		-0.3693
				18,178	9,092		0.5921	▼	414	▼					20,411	12,222		-0.4114
				28,132	34,866		0.548	▼	415	▼					24,248	16,182		-0.4563
				14,836	6,701		0.5016	▼	416	▼					3,458	7,472		-0.5036
				10,147	9,818		0.4534	▼	417	▼					1,997	2,862		-0.5528
				9,941	6,780		0.4043	▼	418	▼					561	2,007		-0.6031
				8,176	8,734		0.3548	▼	419	▼					177	791		-0.6542
				13,732	13,898		0.3061	▼	420	▼					803	492		-0.7046

				<b>CALLS</b>							<b>PUTS</b>							
				<b>Dec 15 '23 (231 days)</b>														
?				0	107	?	0.6251	▼	411	▼	?				8	406	?	-0.4051
				4	303		0.6193	▼	412	▼					14	581		-0.4117
				0	111		0.6134	▼	413	▼					117	185		-0.4185
				0	1,516		0.6075	▼	414	▼					51	1,275		-0.4254
				20	7,599		0.6014	▼	415	▼					682	9,461		-0.4324
				4	10		0.5953	▼	416	▼					11	89		-0.4395
				15	66		0.5891	▼	417	▼					5	722		-0.4467
				0	192		0.5828	▼	418	▼					2	18		-0.4541
				1	254		0.5764	▼	419	▼					1	66		-0.4617
				74	11,459		0.5699	▼	420	▼					38	16,419		-0.4692

WHAT TRENDS SHOULD WE EXPECT?

# INTUITION

SAME STRIKE ~ SIMILAR IV

Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delt	Action	Strike ▲	Action	Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta
<b>CALLS</b>											<b>PUTS</b>							
May 05 '23 (7 days)																		
				6,330	9,442		0.6719	▼	412	▼					23,754	7,102		-0.3305
				8,193	8,007		0.6533	▼	412.5	▼					5,435	6,220		-0.3494
				16,255	13,100		0.6336	▼	413	▼								-0.3383
				18,178	9,092		0.5921	▼	414	▼								
				28,132	34,866		0.548	▼	415	▼					24,248	16,182		-0.4563
				14,836	6,701		0.5016	▼	416	▼					3,458	7,472		-0.5036
				10,147	9,818		0.4534	▼	417	▼					1,997	2,862		-0.5528
				9,941	6,780		0.4043	▼	418	▼					561	2,007		-0.6031
				8,176	8,734		0.3548	▼	419	▼					177	791		-0.6542
				13,732	13,898		0.3061	▼	420	▼					803	492		-0.7046

VOL SKEW  
LOWER STRIKE IV > HIGHER STRIKE IV

MORE TIME  
VALUE IN DEC

Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delt	Action	Strike ▲	Action	Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta
<b>CALLS</b>											<b>PUTS</b>							
Dec 15 '23 (231 days)																		
				0	107		0.6251	▼	411	▼					8	406		-0.4051
				4	303		0.6193	▼	412	▼					14	581		-0.4117
				0	111		0.6134	▼	413	▼					117	185		-0.4185
				0	1,516		0.6075	▼	414	▼					51	1,275		-0.4254
				20	7,599		0.6014	▼	415	▼					682	9,461		-0.4324
				4	10		0.5953	▼	416	▼					11	89		-0.4395
				15	66		0.5891	▼	417	▼					5	722		-0.4467
				0	192		0.5828	▼	418	▼					2	18		-0.4541
				1	254		0.5764	▼	419	▼					1	66		-0.4617
				74	11,459		0.5699	▼	420	▼					38	16,419		-0.4692

# GUTCHECK

SIMILAR IV AT EACH STRIKE

Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta	Action	Strike ▲	Action	Last	Change	Bid	Ask	Volume	Open Int	Imp Vol	Delta	
CALLS										May 05 '23 (7 days)		PUTS						VOL SKEW	
6.39	+1.85	6.28	6.41	6,330	9,442	16.00 %	0.6719	▼	412	▼	1.80	-1.71	1.80	1.82	23,754	7,102	15.82 %	-0.3305	
6.00	+1.76	5.91	6.04	8,193	8,007	15.80 %	0.6533	▼	412.5	▼	1.93	-1.78	1.94	1.95	5,435	6,220	15.64 %	-0.3494	
5.62	+1.71	5.56	5.65	16,255	13,100	15.62 %	0.6336	▼	413	▼	2.08	-1.82	2.08	2.09	15,283	11,916	15.49 %	-0.3693	
4.96	+1.59	4.87	4.92	18,178	9,092	15.24 %	0.5921	▼	414	▼	2.37	-1.88	2.38	2.40	20,411	12,222	15.20 %	-0.4114	
4.27	+1.49	4.22	4.26	28,132	34,866	14.93 %	0.548	▼	415	▼	2.73	-2.11	2.74	2.75	24,248	16,182	14.90 %	-0.4563	
3.64	+1.22	3.62	3.65	14,836	6,701	14.64 %	0.5016	▼	416	▼	3.13	-1.86	3.12	3.15	3,458	7,472	14.62 %	-0.5036	
3.07	+1.07	3.06	3.08	10,147	9,818	14.33 %	0.4534	▼	417	▼	3.56	-2.29	3.54	3.60	1,997	2,862	14.31 %	-0.5528	
2.58	+1.02	2.55	2.57	9,941	6,780	14.08 %	0.4043	▼	418	▼	4.05	-2.95	4.04	4.10	561	2,007	14.04 %	-0.6031	
2.11	+0.81	2.09	2.11	8,176	8,734	13.79 %	0.3548	▼	419	▼	4.54	-2.56	4.57	4.64	177	791	13.71 %	-0.6542	
1.69	+0.69	1.69	1.70	13,732	13,898	13.54 %	0.3061	▼	420	▼	5.25	-2.31	5.12	5.25	803	492	13.33 %	-0.7046	

MORE TIME VALUE IN DEC  
(ONLY 5X COST FOR 33X MORE TIME)

CALLS										Dec 15 '23 (231 days)								
26.71	0.00	32.28	32.67	0	107	18.87 %	0.6251	▼	411	▼	19.16	-1.17	18.50	18.80	8	406	18.95 %	-0.4051
30.50	+0.40	31.59	31.98	4	303	18.77 %	0.6193	▼	412	▼	20.38	-0.99	18.81	19.11	14	581	18.84 %	-0.4117
27.80	0.00	30.91	31.30	0	111	18.67 %	0.6134	▼	413	▼	19.88	-1.01	19.12	19.42	117	185	18.72 %	-0.4185
26.42	0.00	30.23	30.62	0	1,516	18.55 %	0.6075	▼	414	▼	20.33	-1.50	19.44	19.74	51	1,275	18.61 %	-0.4254
29.80	+2.31	29.56	29.94	20	7,599	18.43 %	0.6014	▼	415	▼	19.94	-1.75	19.83	20.06	682	9,461	18.52 %	-0.4324
28.17	+3.83	28.89	29.27	4	10	18.31 %	0.5953	▼	416	▼	20.55	-2.10	20.09	20.40	11	89	18.37 %	-0.4395
28.12	+2.92	28.22	28.60	15	66	18.18 %	0.5891	▼	417	▼	20.50	-2.21	20.42	20.73	5	722	18.24 %	-0.4467
26.21	0.00	27.56	27.94	0	192	18.07 %	0.5828	▼	418	▼	20.88	-1.81	20.77	21.08	2	18	18.15 %	-0.4541
26.66	+2.65	26.91	27.28	1	254	17.95 %	0.5764	▼	419	▼	22.46	-1.33	21.11	21.43	1	66	18.00 %	-0.4617
25.64	+1.09	26.26	26.64	74	11,459	17.84 %	0.5699	▼	420	▼	21.58	-1.41	21.55	21.78	38	16,419	17.92 %	-0.4692

# Summary

## Big Picture

## Applications

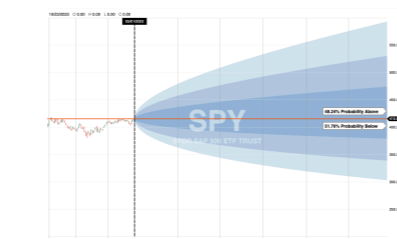
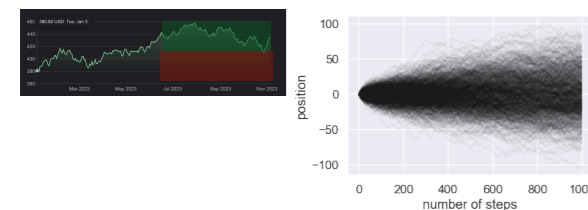
## Detailed Rules Of Thumb

$$C(S, t) = N(d_1)S - N(d_2)Ke^{-rT}$$

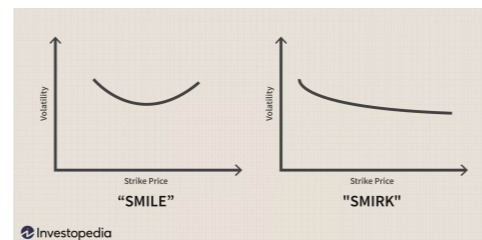
$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$C(S, t)$	(call option price)
$N(\cdot)$	(cumulative distribution function)
$T = (T_1 - t)$	(time left til maturity (in years))
$S$	(stock price)
$K$	(strike price)
$r$	(risk free rate)
$\sigma$	(volatility)



Theta Decay



Intrinsic Value ~  
Vol × √ Time

Rule Of  
68-95-99.7

Also:  
Rule Of 16

- Slides, links available at [betterexplained.com/cboe](https://betterexplained.com/cboe)

# APPENDIX

CALCULATION OF VOLATILITY	
- ANNUAL VOLATILITY CALCULATION	<a href="https://www.investopedia.com/ask/answers/021015/how-can-you-calculate-volatility-excel.asp">HTTPS://WWW.INVESTOPEDIA.COM/ASK/ANSWERS/021015/HOW-CAN-YOU-CALCULATE-VOLATILITY-EXCEL.ASP</a> , <a href="https://www.fool.com/knowledge-center/how-to-calculate-annualized-volatility.aspx">HTTPS://WWW.FOOL.COM/KNOWLEDGE-CENTER/HOW-TO-CALCULATE-ANNUALIZED-VOLATILITY.ASPX</a>
- HISTORICAL VOLATILITY CALCULATION	<a href="https://www.investopedia.com/articles/investing/102715/computing-historical-volatility-excel.asp">HTTPS://WWW.INVESTOPEDIA.COM/ARTICLES/INVESTING/102715/COMPUTING-HISTORICAL-VOLATILITY-EXCEL.ASP</a>
- WHY LOG RETURNS?	<a href="https://quantivity.wordpress.com/2011/02/21/why-log-returns/">HTTPS://QUANTIVITY.WORDPRESS.COM/2011/02/21/WHY-LOG-RETURNS/</a>
VOLATILITY INDEX (VIX)	
- OVERVIEW	<a href="https://www.5minutefinance.org/concepts/the-vix-index">HTTPS://WWW.5MINUTEFINANCE.ORG/CONCEPTS/THE-VIX-INDEX</a> , <a href="https://www.investopedia.com/terms/v/volatility.asp">HTTPS://WWW.INVESTOPEDIA.COM/TERMS/V/VOLATILITY.ASP</a>
- CALCULATION	<a href="https://www.cboe.com/tradable_products/vix/faqs/">HTTPS://WWW.CBOE.COM/TRADABLE_PRODUCTS/VIX/FAQS/</a> , <a href="https://www.spglobal.com/spdji/en/documents/research/research-reading-vix-does-vix-predict-future-volatility.pdf">HTTPS://WWW.SPGLOBAL.COM/SPDJI/EN/DOCUMENTS/RESEARCH/RESEARCH-READING-VIX-DOES-VIX-PREDICT-FUTURE-VOLATILITY.PDF</a>
- RULE OF 16	<a href="https://workplace.schwab.com/resource-center/insights/story/options-volatility-vix-skew-and-rule-16">HTTPS://WORKPLACE.SCHWAB.COM/RESOURCE-CENTER/INSIGHTS/STORY/OPTIONS-VOLATILITY-VIX-SKEW-AND-RULE-16</a>
OPTIONS PRICING	
- WHY ARE PUTS SO EXPENSIVE?	<a href="https://papers.ssrn.com/sol3/papers.cfm?abstract_id=375784">HTTPS://PAPERS.SSRN.COM/SOL3/PAPERS.CFM?ABSTRACT_ID=375784</a>
RANDOM WALK	
- OVERVIEW	<a href="https://galileo.phys.virginia.edu/classes/152.MF1I.SPRING02/randomwalk.htm">HTTPS://GALILEO.PHYS.VIRGINIA.EDU/CLASSES/152.MF1I.SPRING02/RANDOMWALK.HTM</a>
- SIMULATIONS	<a href="http://e.sci.osaka-cu.ac.jp/yoshino/download/rw/gauss.shtml">HTTP://E.SCI.OSAKA-CU.AC.JP/YOSHINO/DOWNLOAD/RW/GAUSS.SHTML</a> , <a href="https://demonstrations.wolfram.com/SimulatingTheSimplerandomWalk/">HTTPS://DEMONSTRATIONS.WOLFRAM.COM/SIMULATINGTHESIMPLERANDOMWALK/</a> , <a href="http://www.rpgroup.caltech.edu/ncbs_pboq/code/t03_stochastic_simulations.html">HTTP://WWW.RPGROUP.CALTECH.EDU/NCBS_PBOQ/CODE/T03_STOCHASTIC_SIMULATIONS.HTML</a>
NORMALIZATION OF STRIKE DISTANCES	<a href="https://moontowermeta.com/using-log-returns-and-volatility-to-normalize-strike-distances/">HTTPS://MOONTOWERMETA.COM/USING-LOG-RETURNS-AND-VOLATILITY-TO-NORMALIZE-STRIKE-DISTANCES/</a>

# BONUS FORMULA: RULE OF 16

- Yearly Vol = Daily Vol  $\times \sqrt{252}$  trading days
- Daily vol  $\sim$  Yearly vol / 16
- Example:
  - VIX = 24 (24% annual vol)
  - Daily vol =  $24 / 16 = 1.5\%$
- This is a 1 std deviation (sigma,  $\sigma$ ) move

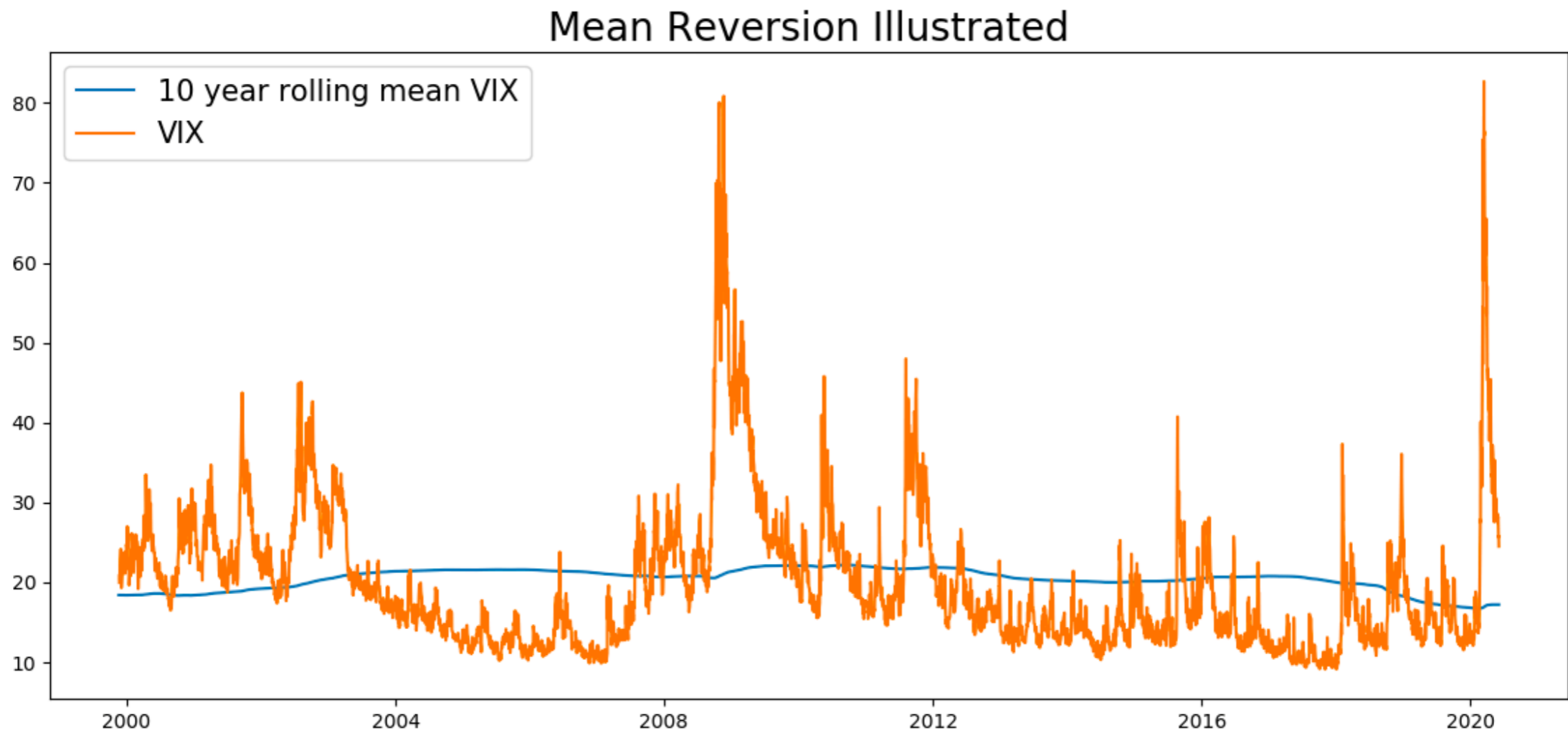


# APPLICATION: MODEL ASSUMPTIONS

MODEL PARAMETER	MODEL ASSUMPTION
TAXES	NONE
DIVIDENDS	NONE
INTEREST RATE	FIXED
TRADING	CONTINUOUS
PRICE CHANGE	RANDOM WALK, CONSTANT VOL
RETURNS	NORMAL DISTRIBUTION

- Black-Scholes model: If assumptions change, volatility arbitrage (vol arb) may occur
  - Buy low / sell high the *implied volatility*, not asset price
- Vega (value change from a vol change)
  - Strategies can be positive, neutral, negative
  - If IV rises enough, both puts and calls can increase in value!
  - Or: sudden options demand driving up IV

# APPLICATION: MEAN REVERSION



Historically, VIX returns to baseline level after events

# ADEPT Method

ANALOGY	Tell me what it's like
DIAGRAM	Help me visualize it
EXAMPLE	Allow me to experience it
PLAIN ENGLISH	Describe it with everyday words
TECHNICAL	Discuss the formal details

For today

- Big-picture overview
- Build working intuition for vol, time, option price
- See a lot of examples / applications
- Dip toes in technical parts (driving, football)

# APPLICATION: VOL DRAG

PORTFOLIO	YEAR 1	YEAR 2	YEAR 3	YEAR 4	ARITHMETIC MEAN (AVG)
A	10%	10%	10%	10%	10%
B	5%	15%	5%	15%	10%
C	0%	20%	0%	20%	10%

(return is year-over-year change)