Volatility Trading System Design with Scaling Risk Management

by

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Submitted to the System Design and Management Program
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Abstract

We propose a volatility trading system that comprises two uncorrelated components. The first component is a straddle long-short strategy which profits by anticipating changes in the volatility of stocks within the SP 500 Index. The second component is a filtered out-of-the-money put writing strategy on the SP 500 Index which profits by collecting premiums while avoiding losses that would occur during market selloffs by using the Absorption Ratio to detect fragile market regimes. We combine these two components into a portfolio by weighting them in such a way that they contribute equally to total portfolio risk. In addition, we include a dynamic hedging overlay to provide further protection to the portfolio.

Thesis Supervisor: Mark P. Kritzman
Title: Senior Lecturer

Contents

Chapter 1

Introduction

Algorithmic trading has grown significantly over the last decade. About 90% of overall trading volume comes from Algorithmic trading in the US market. By estimation, the global algorithmic trading size will grow to USD 18.8 billion by 2024 from USD 11.1 billion in 2019[1]. As a result, designing a reliable trading system which automatically send out trading orders based on quantitative trading strategies is a big challenge nowadays.

We propose an trading system that comprises two uncorrelated trading strategies. The first strategy is a straddle long-short strategy which profits by anticipating changes in the volatility of stocks within the SP 500 Index[2][3]. The second component is a filtered out-of-the-money put writing strategy on the SP 500 Index which profits by collecting premiums while avoiding losses that would occur during market selloffs by using the Absorption Ratio to detect fragile market regimes[4][5]. We combine these two strategies into a portfolio using the Equal Risk Contribution (ERC) method to make them contribute equally to total portfolio risk[6]. Furthermore, we applied a dynamic hedging strategy called Constant Proportion Portfolio Insurance (CPPI) to further control risk[7]. CPPI allows us to maintain exposure to the upside potential of our trading strategies while providing protection against downside risk.

Chapter 2

Design a Trading System

2.1 System Requirements

To successfully develop a trading system, gathering and analyzing system requirements is one of the most important things in the early stage. Properly specified requirements are critical to guide many different aspects of a trading system design project.

Functional Requirements, Performance Requirements and Constraints Requirements are as follows.

Functional Requirements:

1. Collect market data. The system should download, analyze and store financial data, which includes real time market data and historical financial data.

2. Specify trading signals. The system should have indicators, filters and triggers to generate long and short trading signals.

3. Automatic. The trading system should be fully automatic, so it can reduce emotions and preserve discipline all through the trading process.

Performance Requirements:

1. Reward-to-risk ratio.
2. Low correlation among different trading strategies.
3. Quality Metrics such as Sharpe Ratio, Information Ratio, Sortino Ratio.
4. Maximum drawdown length/size.
5. Live trading performance is close to the paper trading performance.
6. Scalability.

Constraints Requirements:

1. The possible markets the system is going to trade (Stock Market, Commodity Futures Market, Foreign Exchange Market).
2. The possible regions the system is going to trade (US Market, European Market, Asian Market).
3. The applicable timeframes(Daily, Minutely, Tick).

2.2 System Architecture of an Automated Trading System

We want to have an Automated Trading System for several reasons:

1. Minimize the effect of emotions. Human emotions, such as fear, greed, and regret, always play a negative role in the trading process. By using automatic trading system to keep emotions in line, traders will follow an established trading strategy easily.

2. Better order execution. In real time trading environment, the market can move swiftly and the price can change. Get in and out of a trade with a few seconds delay can make a large difference in the return rates, especially for intraday trading and high frequency trading. Auto-trading system can send out orders as soon as there is a trading signal. The system should have indicators, filters and triggers to generate long and short trading signals.

3. Diversification. Auto-trading system has the ability to scan for different trading opportunities across different financial markets. It also can monitor different trading accounts simultaneously. The trading risk could be well diversified across strategies and markets.

We define our Auto-Trading system by introducing four different layers: Data Feed Layer, Data Processing Layer, Trading Strategy Layer and Order Execution Layer.

Figure 1. Four Layers of the Auto-Trading System

Figure 2. Trading System Design Process Flowchart

Chapter 3

Straddle Long-Short Strategy

3.1 Strategy Overview

The main idea underlying our straddle long-short strategy is an empirical observation that the term structure of implied volatility plays an important role in determining stock options' returns. Specifically, straddle portfolios with upward slopes in implied volatility term structure outperform those with flatter (or inverted) term structure. We exploit this finding by taking long positions in stock straddles with upward-sloping term structures and short positions in stock straddles with flat or downward sloping term structures[2][3].

3.2 Single Stock Option

An option is an agreement between two parties, the buyer and the seller. Typically, a call stock option allows (optional) the option buyer to buy 100 shares of that stock at the strike price up to the defined expiration date. It also obligates the option seller to sell 100 shares of the stock at the strike price up to the defined expiration date.

Figure 3. Long Call Payoff Diagram

A put stock option, on the other hand, allows (optional) the option buyer to sell 100 shares of that stock at the strike price up to the defined expiration date.It also obligates the option seller to buy 100 shares of the stock at the strike price up to the defined expiration date.

Figure 4. Long put Payoff Diagram

A straddle consists of one long call and one long put. Both options have the same strike price and the same expiration date on the same underlying stocks. A long straddle strategy offers an opportunity to profit from a significant move in either direction in the stock's price. Generally speaking, long straddle means we are betting on rising volatility.

Figure 5. Long Straddle Payoff Diagram

A short straddle strategy offers an opportunity to profit from the stock's price staying relatively the same. Generally speaking, short straddle means we are betting on decreasing volatility.

Figure 6. Short Straddle Payoff Diagram

3.3 Implied Volatility and Term Structure

There are many different kinds of volatility. People focus on historical volatility and implied volatility. Historical volatility Implied volatility is the annualized standard deviation of the stock's historical returns. It measures the historical price changes of the stock. Implied volatility comes from the stock's option prices. It measures the market expectation about the stock's volatility in the future. Implied volatility is an important factor to determine option's price: the higher the implied volatility, the higher the option price.

The term structure of the implied volatility is the implied volatility plotted on different expiration dates. It is another way of looking at the market's expectation on the future volatility. If the implied volatility term structure is upward-sloping, it implies that investors expect to see the volatility of the stock going up in the future. If the term structure is down-sloping, it means people expect a decreasing volatility of the stock.

Figure 7. TSLA Implied Volatility Term Structure

3.4 Economic Hypothesis

The strategy is based on the hypothesis that the slope of the volatility term structure captures market sentiment. For example, investors underestimate volatility in a given company during a quiet period. In this case, the implied volatility of the front-month option would be relatively low compared to the implied volatility of the back-month option, and therefore the at-the-money straddle would be relatively cheap. The opposite happens when there are a lot of company events and investors overreact to volatility. The mispricing in straddle prices are then corrected in the following period[2][3].

3.5 Implementation

We implement the strategy as follows.

1. We collect all options data for SP 500 stocks from the OptionMetrics database.

2. On the day following the standard option expiration date (usually the day after the third Friday of each month), we calculate the slope of Implied Volatility Term Structure (IVTS) for each stock.

3. We then rank these stocks by IVTS and group them into 10 deciles. Group 1 includes stocks with the most upward-sloping term structure (positive slope) and group 10 includes those with the most inverted downward sloping (negative slope).

4. For stocks within group 1, we buy equal dollar amount of one-month ATM straddles and hold them until expiration. For stocks within group 10, we sell short an equal amount of one-month ATM straddles and hold them until expiration.

5. We repeat the process on the day following the expiration day.

3.6 Liquidity and Capital Consideration

To focus on the most liquid stock options, our straddle strategy is implemented with options on stocks within the SP 500 instead of on the full US stock universe. The strategy holds options to maturity, which mitigates transaction costs associated with rebalancing. We further improve liquidity by extending our trading window to 10 business days. Options on single stocks within the SP 500 index have a median daily volume of 1,045. We assume that we will trade 1/10 of the total liquidity on these instruments across 10 business days. We estimate capacity to be $140 million for this straddle long-short strategy.

3.7 Analysis of Strategy Prospects

Our strategy produces a Return/Risk ratio of 1.41 and an annual return of 9.78%. The worst month return was -2.76%. The worst drawdown began in November 2008. The low point of this drawdown was realized in December 2009, at which point the strategy had lost 8.47% from its previous high. The drawdown ended in April 2011, at which point the strategy overcame its previous high-water mark. The strategy has positive returns in 19 years out of 20 historical years.

Figure 8. Straddle Long-Short Strategy vs. SPY Performance

Table 1. 2009-2019 Straddle Long-Short Strategy Return

Chapter 4

Filtered Put Selling Strategy

4.1 Strategy Overview

This strategy is designed to capture option premiums and at the same time reduce exposure to losses that would arise from market downturns. We selectively sell one month out-of-the-money (OTM) SP 500 index put options based on strike price and time to expiration. A critical feature of the strategy is to introduce a timing indicator called the Absorption Ratio which we use to distinguish fragile market regimes from resilient regimes. When fragile conditions prevail, the market is more vulnerable to shocks[4][5].

4.2 Index Option

A stock index is computed from the prices of selected stocks. Different stock indexes can be calculated in different ways. The three most widely known indexes are the SP 500 Index, Dow Jones Industrial Average Index, and Nasdaq Composite Index.

Whereas stock options are based on single stocks, index options are based on a stock index, which measures the performance of the overall market. Unlike stock options, index options are always Cash-Settled.Actual physical delivery of the underlying asset is not required for cash settlement.

4.3 Cboe SP 500 PutWrite Index

In June 2007 the Cboe Options Exchange (Cboe) started to publish the SP 500 PutWrite Index. It is a benchmark index that measures the performance of a hypothetical portfolio that sell a sequence of one-month, at-the-money, SP 500 Index puts and invest cash at short-term Treasury Bill rates.

Figure 9. CBOE SP 500 Put Write Index vs. SPY

We can see from the picture that this write index has a better performance compared to the underlying SP 500 stock index.

4.4 Absorption Ratio

Absorption Ratio is created by Mark Kritzman et al and defined as the percentage of US stocks' variation captured by the first 2 eigenvectors[5]:

Figure 10. Absorption Ratio Formula

We performed our analysis on the historical data on MSCI US sector index's 10 GICS sectors (level I) ranging from 12/31/1999 to date. In addition, we use AR shift instead of AR itself as a market indicator, as research shows that AR's change rate reflects market systemic risk more accurately than its level.

Based on their performance on different indicators, we group SP 500 stocks into the top 20% and the bottom 80%. For each group, we calculated the average SPY return for that period.

Figure 11. Factor Significance in SPY Returns

The result shows on average absorption ratio has the best performance in differentiating the returns.

4.5 Economic Hypothesis

The CBOE SP 500 put write index offers persuasive evidence that selling puts enhances return compared to the market benchmark. Furthermore, evidence suggests that profits from shorting front-month out-of-money (OTM) put options are highly concentrated in the last few days (e.g. last 5 days) before their expiration[4]. Although this strategy is expected to be profitable on average across market cycles, we aim to improve it by scaling exposure to the strategy based on the Absorption Ratio which effectively distinguishes fragile regimes from resilient ones.

4.6 Implementation

We implement the strategy as follows.

1. We collect option price data for SPX index from OptionMetrics database.

2. At the end of every month, we calculate the Absorption Ratio based on MSCI Sector Indexes.

3. If the Absorption Ratio indicates the market is resilient (AR <=1), we sell a front-month out of the money (OTM) put option with five days to expiration and hold the option until expiration.

4. If the Absorption Ratio indicates the market is fragile (AR >1), we clear our position in order to avoid the potential risk.

5. If the SPX index settles above the option's strike price, which indicates the option expires worthless, we collect the 2% monthly return from option premium.

6. If the SPX index falls under the strike price, which means the option would be exercised, we calculate the profit/loss based on the SPX index settlement price.

4.7 Liquidity and Capital Consideration

Our put selling strategy trades SPX index options, which are very liquid. Our strategy holds options to maturity, which mitigates transaction costs associated with rebalancing. We further improve liquidity by extending our trading window to three business days. SPX front-month out of the money (OTM) put options have an average daily volume of 8,000. We assume that we will trade 1/10 of the total liquidity on these instruments across three business days. We estimate capacity to be 450 million for this put selling strategy.

4.8 Analysis of Strategy Prospects

Our strategy produced a Return/Risk Ratio of 1.08 and 1.22, with and without absorption ratio respectively. For the strategy with absorption ratio, the annual return is 9.64%. The worst drawdown improved from -42.19% to -16.34% with the Absorption Ratio. The worst drawdown, also the worst single month return, happened in August 2015. The strategy has positive returns in 17 years out of 20 historical years.

Figure 12. Filtered Put Selling Strategy vs. SPY Performance

Table 2. 2000-2019 Filtered Put Selling Strategy Return

Chapter 5

Portfolio Construction and Constant Proportion Portfolio Insurance(CPPI)

5.1 Equal Risk Contribution

We have many options to construct a portfolio. (PIC) Among them, Equal Risk Contribution(ERC) approach is attractive because it applies measures of volatility and correlation to find the optimal sizing, which actively diversifies risk of the portfolio. ERC will give each asset/strategy the weight in which each asset/strategy contributes the same amount of risk to our portfolio. One of the benefits of using ERC, is that it does not require us to input the expected return numbers as inputs, which makes the ERC approach more robust than others[6].

5.2 Portfolio Construction

We combine our two strategy components into a portfolio by weighting them such that they contribute equally to total portfolio risk, except for the first 24-month period in which case we weight them equally.(Maillard,2008) We measure their risk based on the prior 24 monthly returns on a rolling monthly basis. Our ERC portfolio produces a Return/Risk ratio of 1.92. The worst month return was -7.76%. The worst drawdown began in November 2018. The low point of this drawdown was realized in

February 2019, at which point the strategy had lost 10.24% from its previous high. The drawdown ended in December 2019, at which point the strategy overcame its previous high-water mark.

Figure 13. Equal Risk Contribution (ERC) Portfolio Return vs. SPY Return

Figure 14. ERC Portfolio Drawdown vs. SPY Drawdown

5.3 Diversification

Our portfolio is exposed to volatility and market concentration risk. We attempt to mitigate these risks through diversification and dynamic hedging.

The two strategies have a slightly negative correlation of -0.0566. By constructing a portfolio using the equal risk contribution methodology as discussed above, our portfolio's annual volatility decreases from 6.81% and 7.81% for the individual strategies respectively, to 5.08% for combined portfolio.

Figure 15. Strategy I Strategy II Returns

Figure 16. Risk vs. Return Relationship for Different Strategies

5.4 Construction and Constant Proportion Portfolio Insurance(CPPI)

We implement a portfolio insurance strategy called Constant Proportion Portfolio Insurance (CPPI) to add further protection to the portfolio (Perold,1986). CPPI allows us to maintain an exposure to the upside potential of our trading strategies while providing protection against downside risk. According to CPPI, we invest an amount equal to the product of a multiplier and cushion (portfolio value minus floor) in our trading strategies and invest the remainder in the 3-month Treasury Bill. When the portfolio value is below the floor (90%), we move all the portfolio assets into a 3-month Treasury Bill. When the portfolio value is above the floor, we invest an amount equal to the cushion times the multiplier in the trading strategies with the balance allocated to Treasury Bills[7].

Figure 17. Portfolio Performance with CPPI

Chapter 6

Summary

We propose two option trading strategies. The first one profits from anticipated changes in stock volatility, through long-short straddles. It yields an annual return of 9.78% with a return/risk ratio of 1.41 and a max drawdown of -8.47% (see Figure 1). The second strategy profits from writing out-of-the-money put options on the SP 500 Index. Furthermore, we used the Absorption Ratio, which measures the resilience of the market, to avoid losses during fragile regimes. The second strategy produces an annual return of 9.64% with a return/risk ratio of 1.22 and a max drawdown of -16.34% (see Figure 3). We combine these two strategies into a portfolio using the Equal Risk Contribution (ERC) method. The resulting portfolio has an improved risk-return profile with an annual return of 10.08% and a return/risk ratio of 1.92. The max drawdown improved to -10.24% (see Figure 4). We applied a dynamic hedging strategy called Constant Proportion Portfolio Insurance (CPPI) to further control risk. CPPI allows us to maintain exposure to the upside potential of our trading strategies while providing protection against downside risk. The CPPI improved maximum drawdown from -10.24% to -8.16%. Additionally, our portfolio exhibits a positive return during all years during our back-testing period from 2000 to 2019.

Appendix A

Tables

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Annual Return	22.0%	9.9%	25.4%	4.0%	3.2%	11.6%	8.1%	16.7%	18.1%	-6.2%
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual Return	4.4%	6.5%	11.0%	17.1%	10.8%	14.8%	2.5%	2.1%	9.2%	3.4%

Table 1 2009-2019 Straddle Long-Short Strategy Return

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Annual Return	26.3%	-3.9%	0.0%	10.4%	6.1%	20.0%	4.0%	8.2%	8.2%	13.7%
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual Return	8.2%	17.8%	10.6%	-1.7%	26.8%	-10.0%	17.2%	26.8%	2.3%	10.7%

Table 2 2000-2019 Filtered Put Selling Strategy Return

Appendix B

Figures

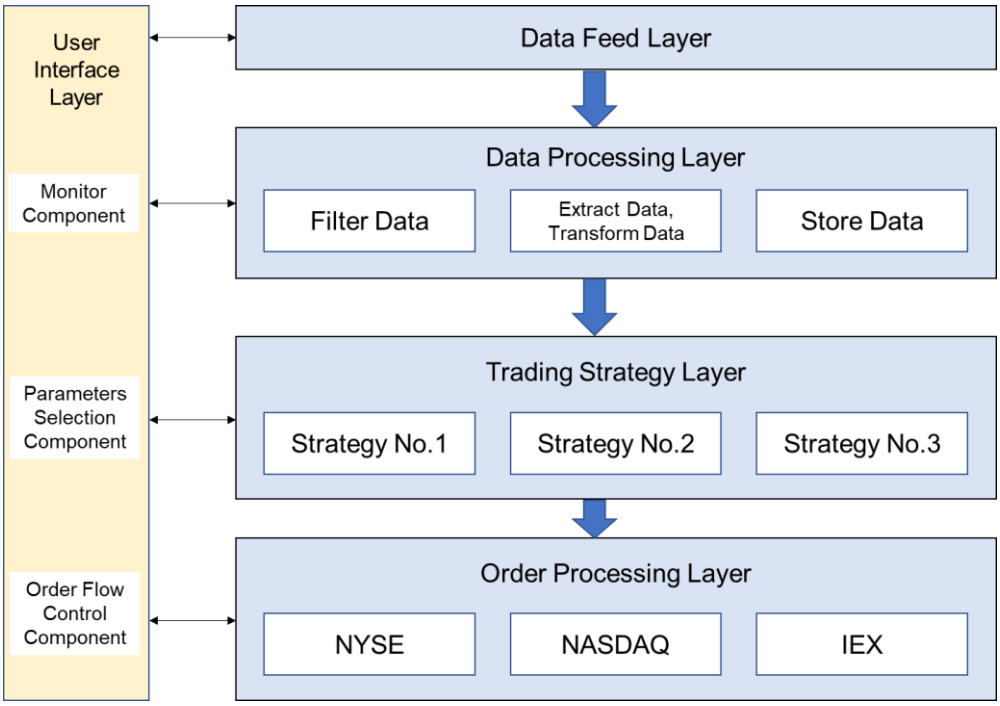


Figure 1. Four Layers of the Auto-Trading System

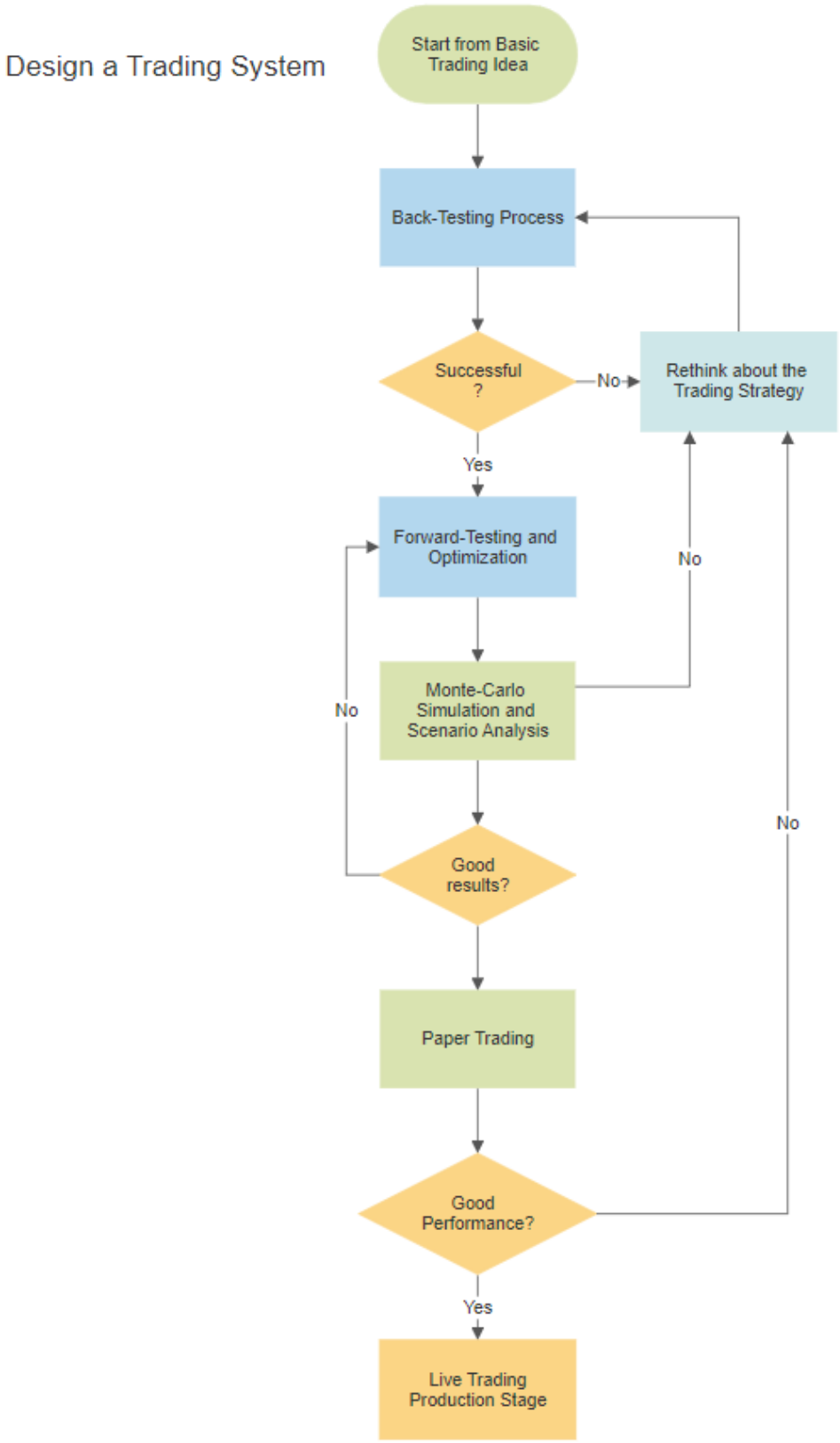


Figure 2. Trading System Design Process Flowchart

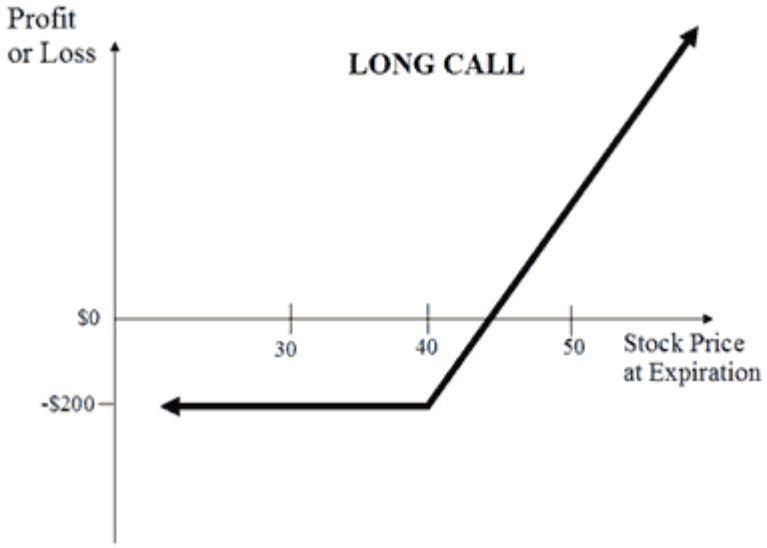


Figure 3. Long Call Payoff Diagram

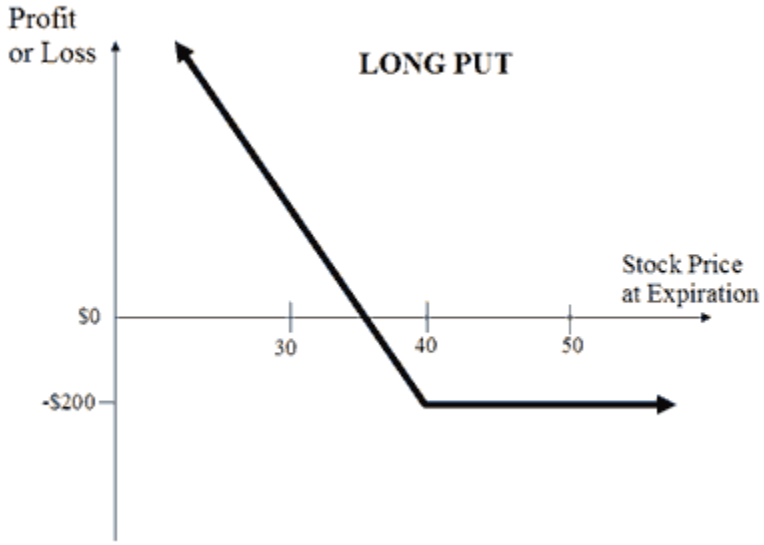


Figure 4. Long put Payoff Diagram

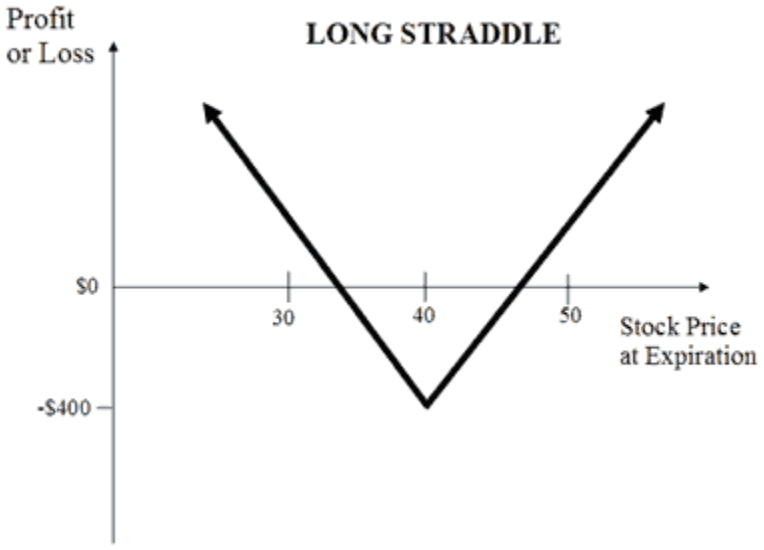


Figure 5. Long Straddle Payoff Diagram

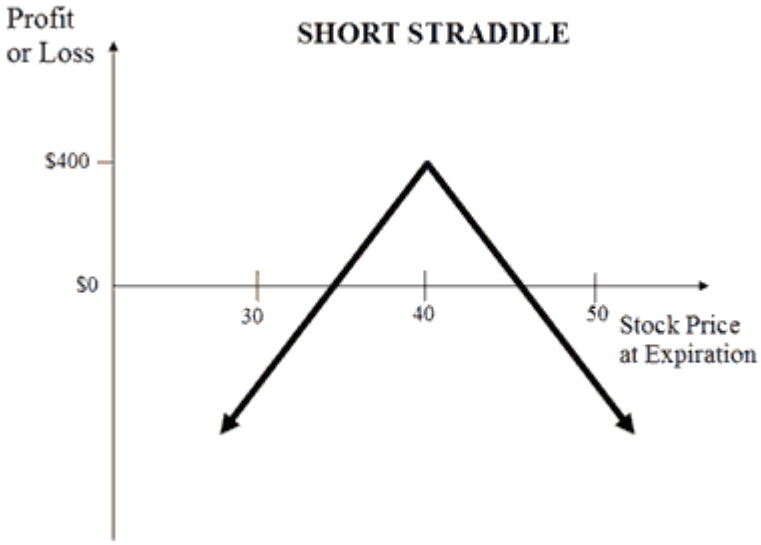


Figure 6. Short Straddle Payoff Diagram

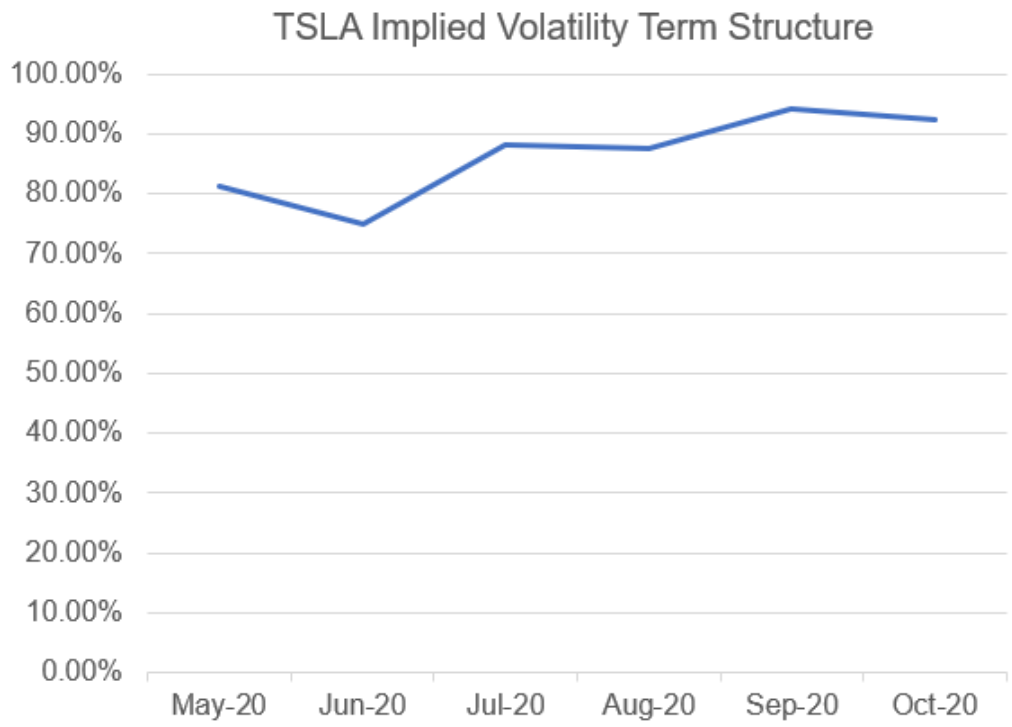
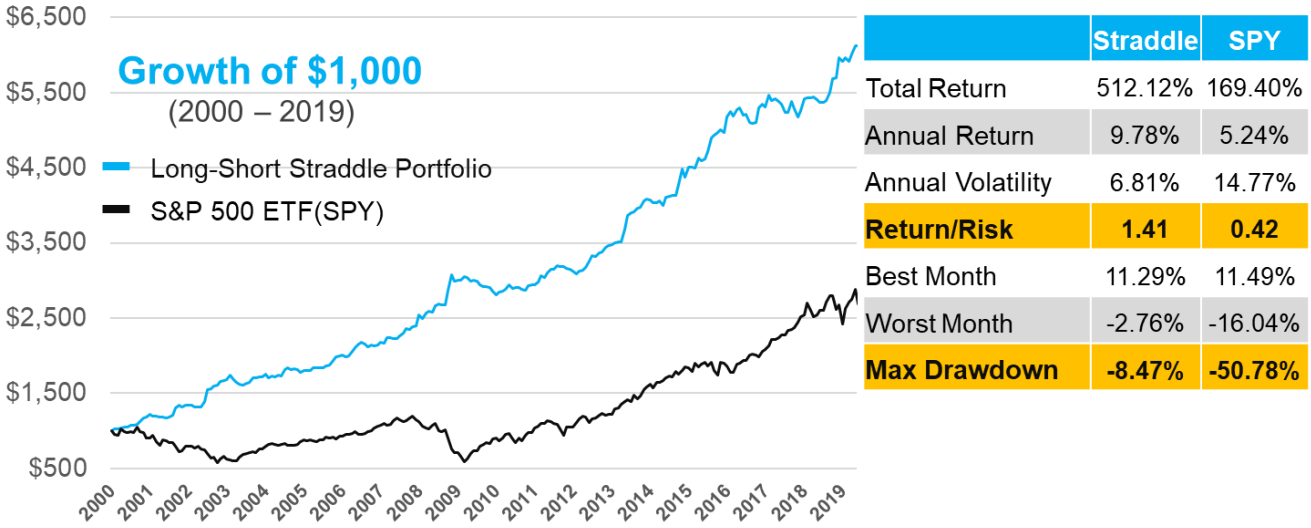


Figure 7. TSLA Implied Volatility Term Structure



	Straddle	SPY
Total Return	512.12%	169.40%
Annual Return	9.78%	5.24%
Annual Volatility	6.81%	14.77%
Return/Risk	**1.41**	**0.42**
Best Month	11.29%	11.49%
Worst Month	-2.76%	-16.04%
Max Drawdown	**-8.47%**	**-50.78%**

Figure 8. Straddle Long-Short Strategy vs. SPY Performance

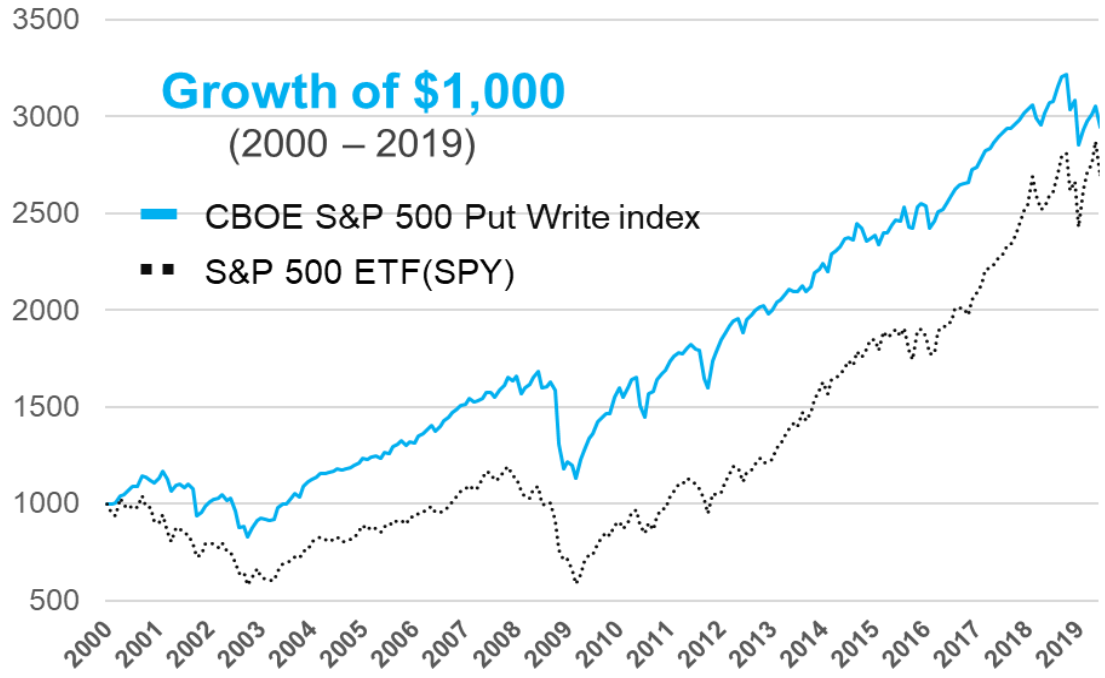


Figure 9. CBOE S&P 500 Put Write Index vs. SPY

$$AR = \frac{\sum_{i=1}^{n} \sigma_{E_i}^2}{\sum_{j=1}^{N} \sigma_{A_j}^2}$$

AR:	Absorption ratio
N:	Number of assets
n:	Number of eigenvectors used to calculate AR
$\sigma_{E_i}^2$:	Variance of the i-th eigenvector, sometimes called eigenportfolio
$\sigma_{A_j}^2$:	Variance of the j-th asset

Figure 10. Absorption Ratio Formula

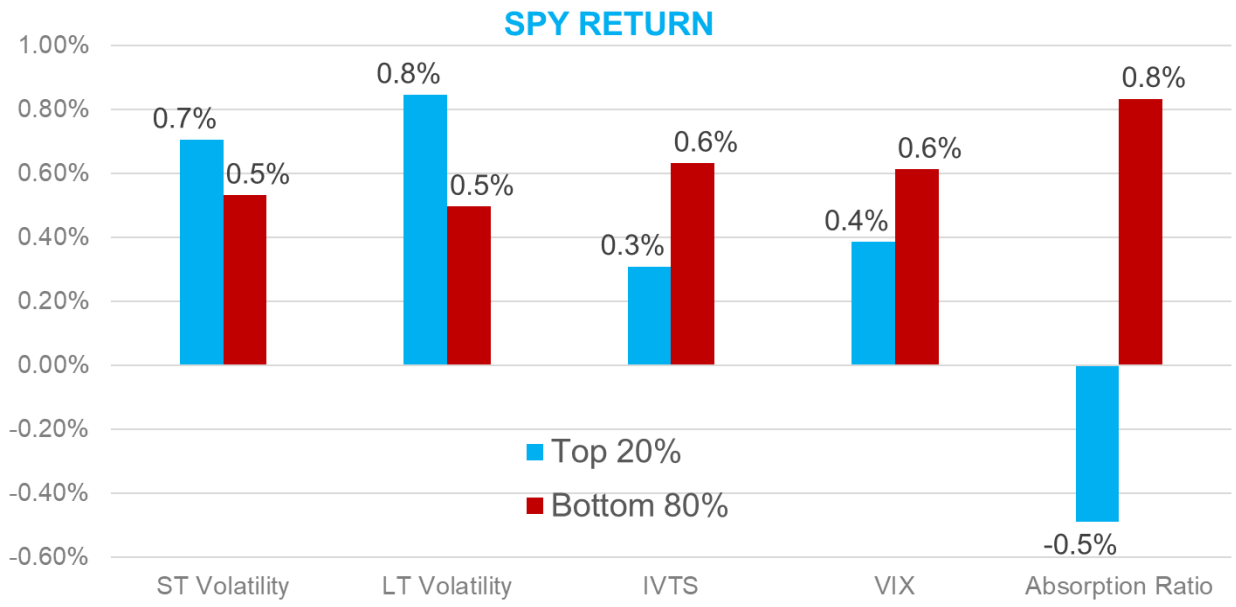
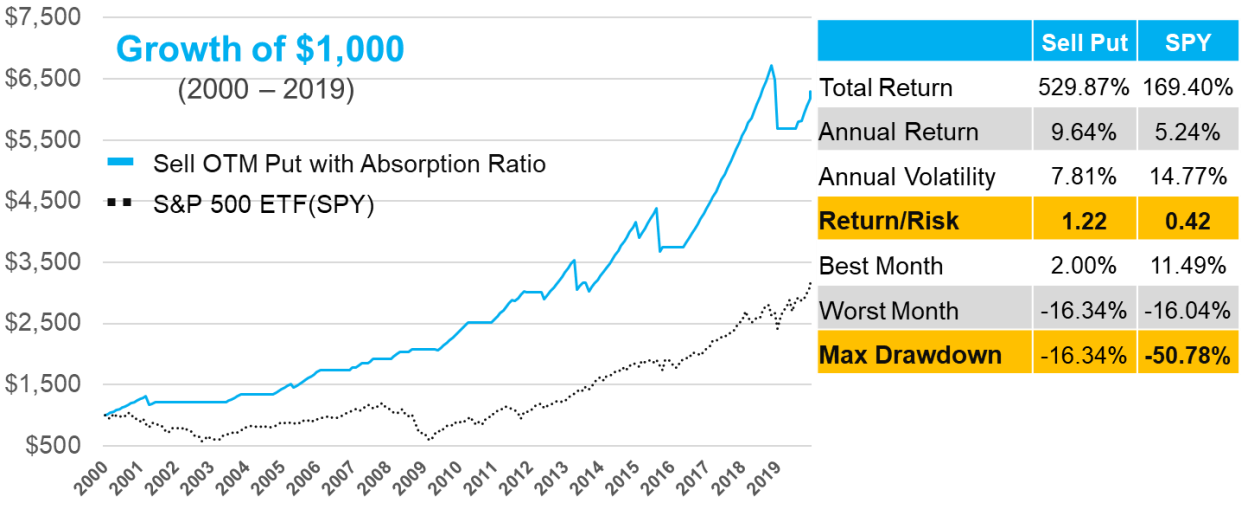
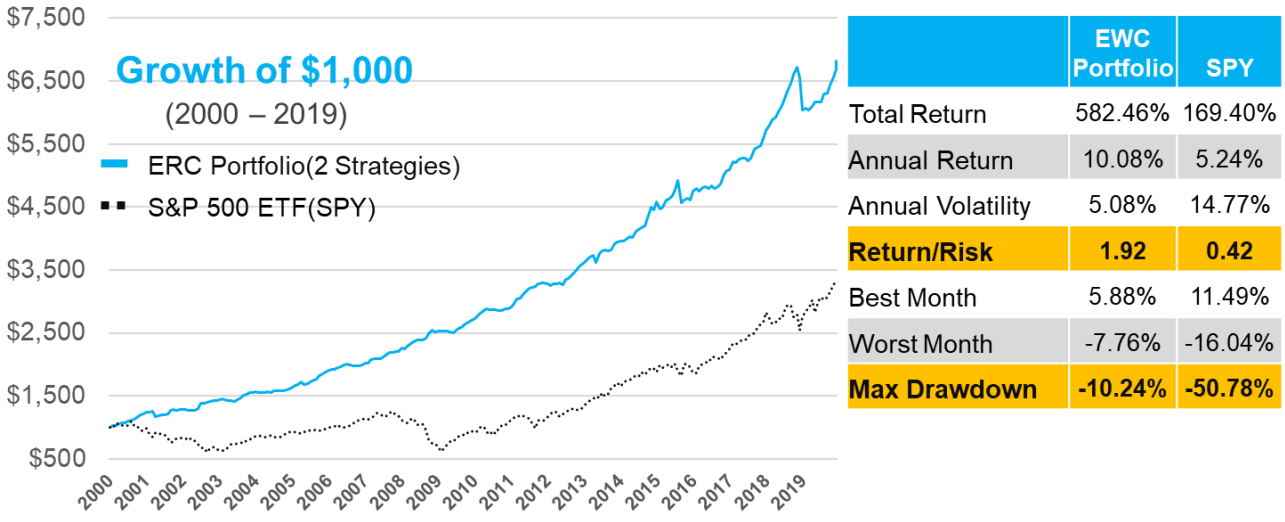


Figure 11. Factor Significance in SPY Returns



	Sell Put	SPY
Total Return	529.87%	169.40%
Annual Return	9.64%	5.24%
Annual Volatility	7.81%	14.77%
Return/Risk	**1.22**	**0.42**
Best Month	2.00%	11.49%
Worst Month	-16.34%	-16.04%
Max Drawdown	-16.34%	**-50.78%**

Figure 12. Filtered Put Selling Strategy vs. SPY Performance



	EWC Portfolio	SPY
Total Return	582.46%	169.40%
Annual Return	10.08%	5.24%
Annual Volatility	5.08%	14.77%
Return/Risk	**1.92**	**0.42**
Best Month	5.88%	11.49%
Worst Month	-7.76%	-16.04%
Max Drawdown	**-10.24%**	**-50.78%**

Figure 13. Equal Risk Contribution (ERC) Portfolio Return vs. SPY Return

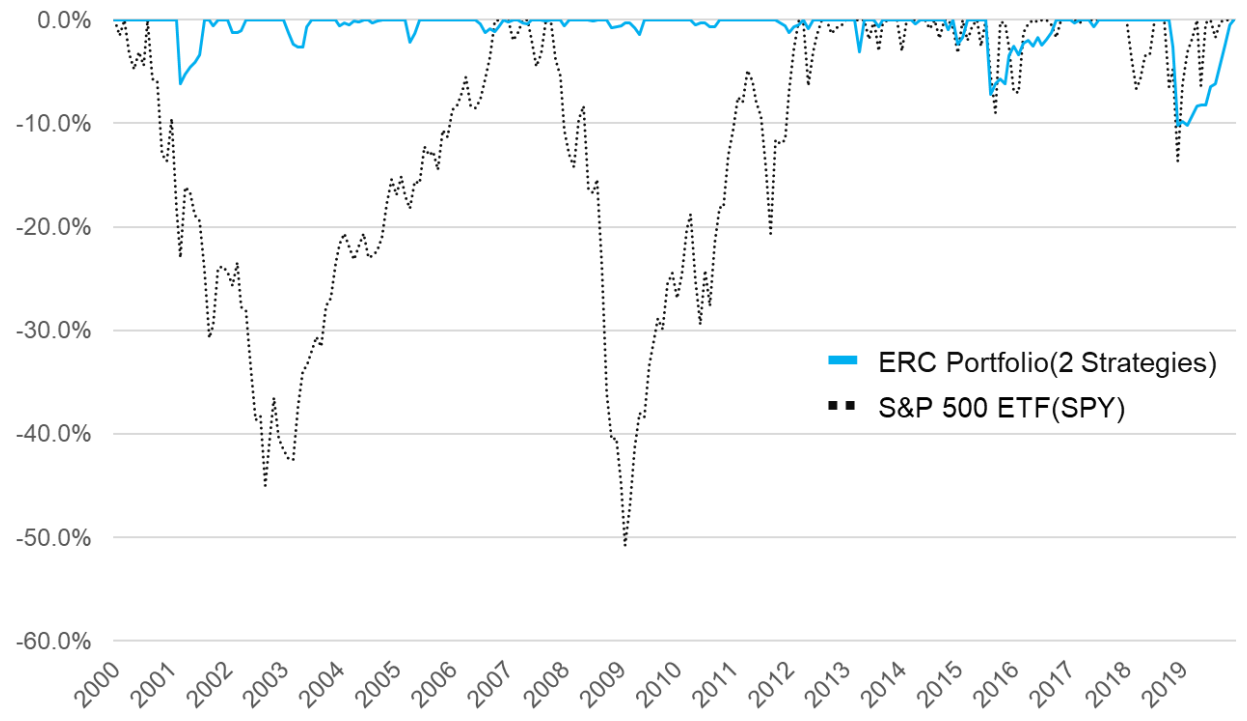


Figure 14. ERC Portfolio Drawdown vs. SPY Drawdown

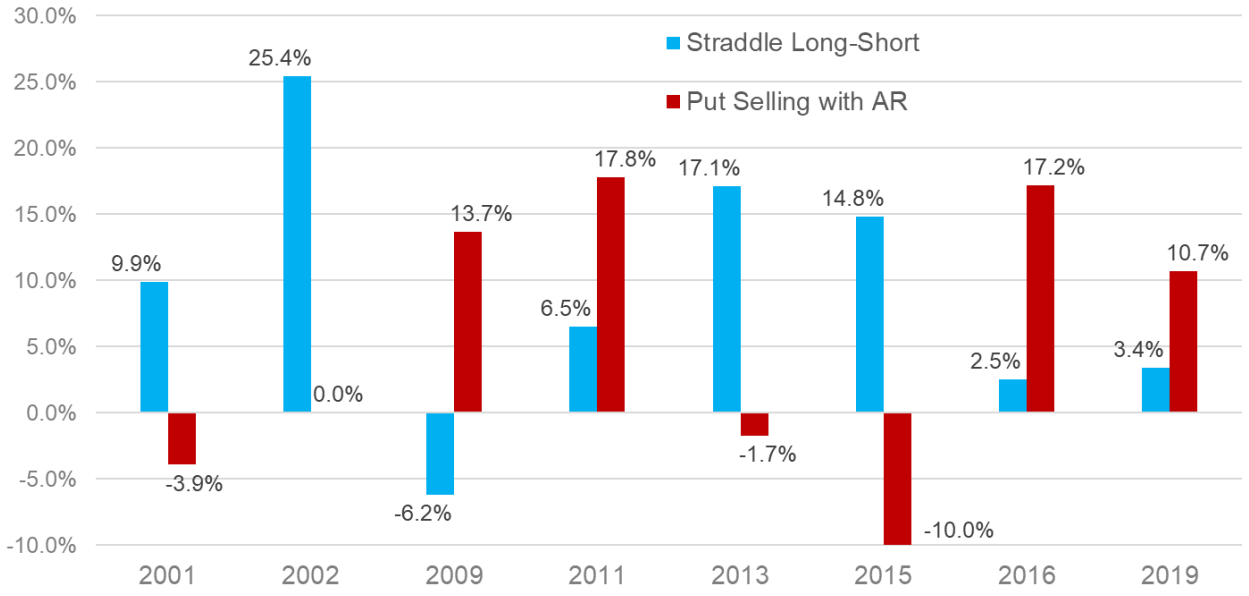


Figure 15. Strategy I & Strategy II Returns

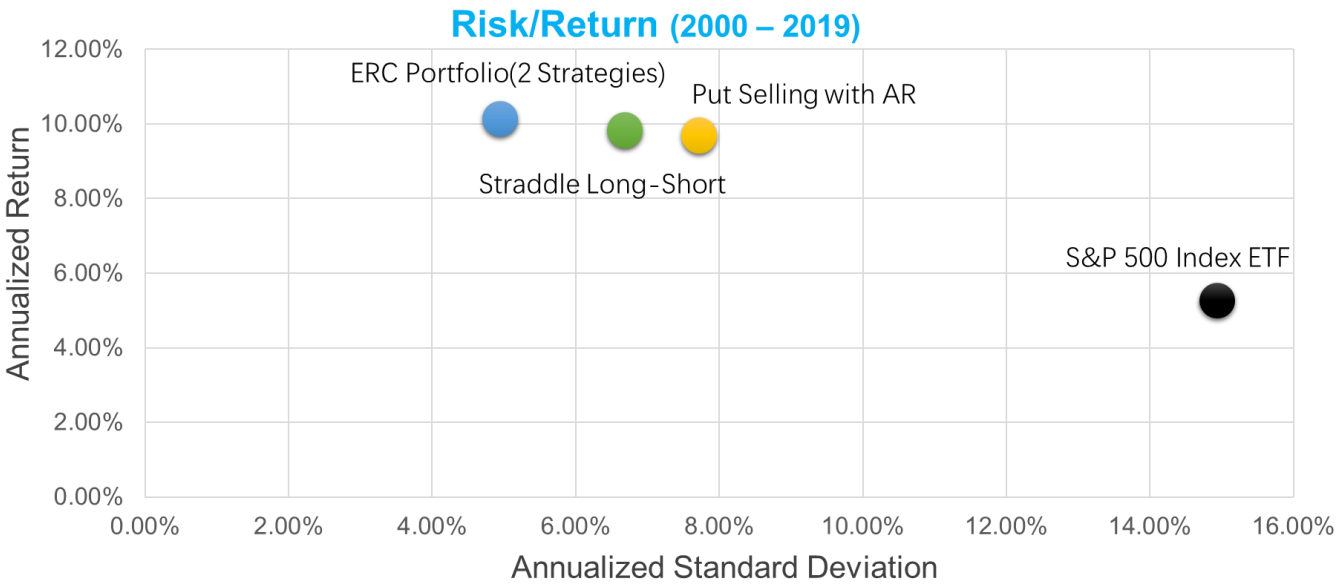
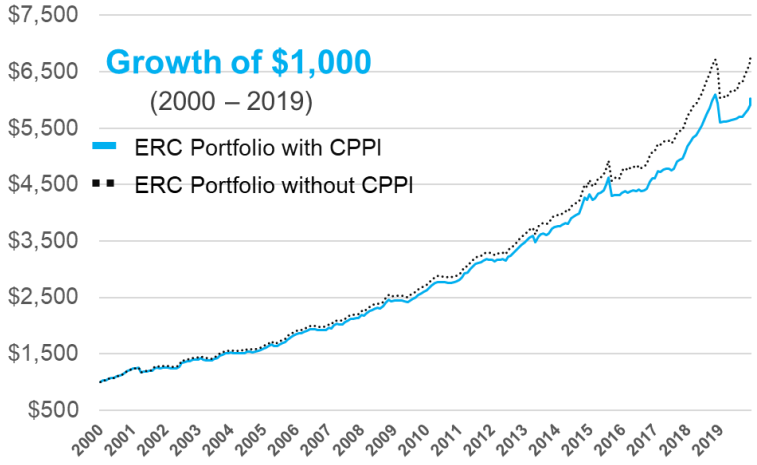


Figure 16. Risk vs. Return Relationship for Different Strategies



	CPPI	ERC	SPY
Total Return	502.46%	582.46%	169.40%
Annual Return	9.39%	10.08%	5.24%
Annual Volatility	4.73%	5.08%	14.77%
Return/Risk	**1.93**	**1.92**	**0.42**
Best Month	5.88%	5.88%	11.49%
Worst Month	-7.23%	-7.76%	-16.04%
Max Drawdown	**-8.16%**	**-10.24%**	**-50.78%**

Figure 17. Portfolio Performance with CPPI

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