151 Trading Strategies

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(August 17, 2018)

ZK: To my mother Mila and my children Mirabelle and Maximilien

JAS: To my parents, Claudio and Andrea, and my brother Emiliano

Abstract

We provide detailed descriptions, including over 550 mathematical formulas, for over 150 trading strategies across a host of asset classes (and trading styles). This includes stocks, options, fixed income, futures, ETFs, indexes, commodities, foreign exchange, convertibles, structured assets, volatility (as an asset class), real estate, distressed assets, cash, cryptocurrencies, miscellany (such as weather, energy, inflation), global macro, infrastructure, and tax arbitrage. Some strategies are based on machine learning algorithms (such as artificial neural networks, Bayes, k-nearest neighbors). We also give: source code for illustrating out-of-sample backtesting with explanatory notes; around 2,000 bibliographic references; and over 900 glossary, acronym and math definitions. The presentation is intended to be descriptive and pedagogical.

This is a preview version containing parts of the following book:
Z. Kakushadze and J.A. Serur. *151 Trading Strategies.* Cham, Switzerland: Palgrave Macmillan, an imprint of Springer Nature, 1st Edition (2018), XX, 480 pp; ISBN 978-3-030-02791-9. Full version: `https://www.springer.com/us/book/9783030027919`.

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Praises of *151 Trading Strategies*

"If you want to work as a trader or quant on Wall Street, you have to walk the walk and talk the talk. This unique book is a comprehensive introduction to a wide variety of tried and tested trading strategies. I highly recommend a 152nd trading strategy called buy this book!"

–**Peter Carr**, Professor and Chair of Finance and Risk Engineering Department, NYU's Tandon School of Engineering; and 2010 Financial Engineer of the Year, International Association for Quantitative Finance & Sungard

"This book is an encyclopedic guided tour of "quant" investment strategies, from the simplest ones (like trend following) to much more exotic ones using sophisticated derivative contracts. No claim is made about the profitability of these strategies: one knows all too well how much implementation details and transaction costs matter. But no quant trader can afford ignoring what's out there, as a source of inspiration or as a benchmark for new ideas."

–**Jean-Philippe Bouchaud**, Chairman and Chief Scientist, Capital Fund Management; Professor, École Normale Supérieure; Member, French Academy of Sciences; and Co-Director, CFM-Imperial Institute of Quantitative Finance

"Zura Kakushadze and Juan Andrés Serur have created a masterful encyclopedia of quantitative trading strategies. The authors offer us a rigorous but accessible treatment of the mathematical foundations of these strategies. The coverage is comprehensive, starting with simple and well-known strategies such as covered call and then moving naturally to strategies involving cryptocurrencies. The supporting material such as a detailed glossary and an extensive list of references will make this book an essential reference for financial economists and investment professionals."

–**Hossein Kazemi**, Michael & Cheryl Philipp Endowed Professor of Finance, University of Massachusetts at Amherst; and Editor-in-Chief, *The Journal of Alternative Investments*

"The successful trading of financial instruments is both a science and an art, just as the efforts of a chef reflect both gastronomic artistry and the underlying chemical and thermal processes of cooking. In *151 Trading Strategies* financial traders are provided with a compendium of sound recipes, spanning the broad range of methods that can be applied to modern investment practice. The exposition of both the mathematics and intuition of each described trade is clear and concise. Readers will appreciate the inclusion of extensive computer code so as to reduce effort needed to implement any required calculations."

–**Dan diBartolomeo**, President, Northfield Information Systems; and Editor, *Journal of Asset Management*

"A real tour de force–*151 Trading Strategies* provides the most comprehensive un-

covering of popular hedge fund strategies. By revealing all the hedge funds' secret sauce, Kakushadze and Serur have now rendered everything as beta-strategies. Time to lower 'em fees!"

–**Jim Kyung-Soo Liew**, Assistant Professor of Finance, Carey Business School, Johns Hopkins University; Advisory Board Member, *The Journal of Portfolio Management*; and Co-Founder, SoKat

"This book is an impressive concentration of strategies and formulas to expand knowledge in quantitative finance; it's a must-read for anyone who wants to drastically improve his or her expertise in financial markets dynamics."

–**Daniele Bernardi**, CEO, DIAMAN Capital; and Chairman of the Board, *INVESTORS' Magazine Italia*

1 Introduction and Summary

A trading strategy can be defined as a set of instructions to achieve certain asset holdings by some predefined times $t_1, t_2, \ldots$, which holdings can (but need not) be null at one or more of these times. In many cases, the main objective of a trading strategy is to make a profit, i.e., to generate a positive return on its investment. However, some viable trading strategies are not always outright profitable as stand-alone strategies. E.g., a hedging strategy can be a part of a bigger plan, which itself can but need not be a trading strategy. Thus, an airline hedging against rising fuel costs with commodity futures is a trading strategy, which is a risk-management step in executing the airline's business strategy of generating profits through its services.

In the case of trading strategies that are intended to be outright profitable as stand-alone strategies, one may argue that the phrase "buy low, sell high" captures their essence. However this viewpoint is somewhat superfluous and, while it applies to trading strategies that buy and sell a single asset (e.g., a single stock), it would exclude a whole host of viable strategies that do not work quite like that. E.g., a trading strategy that uses a hedging sub-strategy for risk management may not always "buy low, sell high" when it comes to a particular asset in its portfolio. This is because hedging risk – or, essentially, transferring some risk to other market participants – is not free, and often a trader will pay a premium for hedging some risks in a trading strategy to achieve its objectives. Another example would be the so-called statistical arbitrage, wherein the trading portfolio can consist of, e.g., thousands of stocks and profitability is typically not achieved by buying low and selling high each stock or even any discernable groups of stocks, but statistically, across all stocks, with some trades making money and some losing it. It gets complicated quickly.

The purpose of these notes is to collect a variety of trading strategies in the context of finance (as opposed to trading baseball cards, classic cars, etc.) across essentially all (or at least most frequently encountered) asset classes. Here we deliberately use the term "asset class" somewhat loosely and include what can be referred to as "asset sub-classes". Thus, a narrower definition would include stocks, bonds, cash, currencies, real estate, commodities and infrastructure. However, this definition would be too narrow for our purposes here. We also consider: derivatives such as options and futures; exchange-traded funds (ETFs); indexes (which are usually traded through vehicles such as ETFs and futures); volatility, which can be treated as an asset class (and traded via, among other things, exchange-traded notes); structured assets (such as collateralized debt obligations and mortgage-backed securities); convertible bonds (which represent a hybrid between bonds and stocks); distressed assets (which are not a separate asset class per se, but the corresponding trading strategies are rather distinct); cryptocurrencies; miscellaneous assets such as weather and energy (derivatives); and also trading strategies such as tax arbitrage and global macro (which use some assets mentioned above as tradables). Some strategies are relatively simple and can be described in words, while many (in fact, most) require a much more detailed mathematical description, which we provide formulaically.

It is important to bear in mind that, unlike the laws of nature (physics), which (apparently) are set in stone and do not change in time, financial markets are man-made and change essentially continuously, and at times quite dramatically. One of the consequences of this transiency is that trading strategies that may have worked well for some time, may die, sometimes quite abruptly. E.g., when the New York Stock Exchange (NYSE) started switching away from its human-operated "specialist" system to electronic trading beginning late 2006,[4] many statistical arbitrage strategies that were profitable for years prior to that, pretty much died overnight as volatility increased and what used to do the trick before no longer did. Eventually the market was flooded with high frequency trading (HFT)[5] strategies further diminishing profit margins of many "good old" trading strategies and killing them.

However, technological advances gave rise to new types of trading, including ubiquitous trading strategies based on data mining and machine learning, which seek to identify – typically quite ephemeral – signals or trends by analyzing large volumes of diverse types of data. Many of these trading signals are so faint that they cannot be traded on their own, so one combines thousands, in fact, tens or even hundreds of thousands if not millions of such signals with nontrivial weights to amplify and enhance the overall signal such that it becomes tradable on its own and profitable after trading costs and slippage, including that inflicted by HFT.[6]

Considering the intrinsically ephemeral nature of the financial markets and trading strategies designed to make a profit therefrom, the purpose of these notes is *not* to convey to the reader how to make money using any trading strategy but simply to provide information on and give some flavor of what kind of trading strategies people have considered across a broad cross-section of asset classes and trading styles. In light of the foregoing, we make the following DISCLAIMER: *Any information or opinions provided herein are for informational purposes only and are not intended, and shall not be construed, as an investment, legal, tax or any other such advice, or an offer, solicitation, recommendation or endorsement of any trading strategy, security, product or service.* For further legal disclaimers, see Appendix B hereof.

We hope these notes will be useful to academics, practitioners, students and aspiring researchers/traders for years to come. These notes intentionally – not to duplicate prior literature and to avoid this manuscript spanning thousands of pages – do not contain any numeric simulations, backtests, empirical studies, etc. However, we do provide an eclectic cornucopia of references, including those with detailed empirical analyses. Our purpose here is to describe, in many cases in sizable detail, various trading strategies. Also, Appendix A provides source code for illustrating out-of-sample backtesting (see Appendix B for legalese).[7] So, we hope you enjoy!

[4] NYSE first started with its "Hybrid Market" (see, e.g., [Hendershott and Moulton, 2011]). However, the writing had been on the wall for the ultimate demise of the specialist system for quite some time. For a timeline, see, e.g., [Pisani, 2010].

[5] See, e.g., [Aldridge, 2013], [Lewis, 2014].

[6] See, e.g., [Kakushadze and Tulchinsky, 2016], [Kakushadze and Yu, 2017b].

[7] The code in Appendix A is not written to be "fancy" or optimized for speed or otherwise.

2 Options

2.1 Generalities

An option is a form of a financial derivative. It is a contract sold by the option writer to the option holder. Typically, an option gives the option holder the right, but not the obligation, to buy or sell an underlying security or financial asset (e.g., a share of common stock) at an agreed-upon price (referred to as the strike price) during a certain period of time or on a specific date (referred to as the exercise date). A buyer pays a premium to the seller for the option. For option pricing, see, e.g., [Harrison and Pliska, 1981], [Baxter and Rennie, 1996], [Hull, 2012], [Kakushadze, 2015a].

A European call option is a right (but not an obligation) to buy a stock at the maturity time T for the strike price k agreed on at time $t = 0$. The claim for the call option $f^{call}(S_T, k) = (S_T - k)^+$. Here $(x)^+ = x$ if $x > 0$, and $(x)^+ = 0$ if $x \leq 0$. By the "claim" we mean how much the option is worth at maturity T. If the stock price at maturity $S_T > k$, then the option holder gains $S_T - k$ (excluding the cost paid for the option at $t = 0$). If the price at maturity $S_T \leq k$, then there is no profit to be made from the option as it makes no sense to exercise it if $S_T < k$ (as it is cheaper to buy the stock in the market) and it makes no difference if $S_T = k$ – all this is assuming no transaction costs. Similarly, a European put option is a right (but not an obligation) to sell a stock at the maturity time T for the strike price k agreed on at time $t = 0$. The claim for the put option is given by $f^{put}(S_T, k) = (k - S_T)^+$.

Options can be issued on a variety of underlying assets, e.g., equities (single-stock options), bonds, futures, indexes, commodities, currencies, etc. For the sake of terminological convenience and definiteness, in the following we will frequently refer to the underlying asset as "stock", even though in many cases the discussion can be readily generalized to other assets. Furthermore, there is a variety of option styles (beyond European options – for European options, see, e.g., [Black and Scholes, 1973]), e.g., American options (that can be exercised on any trading day on or before expiration – see, e.g., [Kim, 1990]), Bermudan options (that can be exercised only on specified dates on or before expiration – see, e.g., [Andersen, 1999]), Canary options (that can be exercised, say, quarterly, but not before a determined time period, say, 1 year, has elapsed – see, e.g., [Henrard, 2006]), Asian options (whose payoff is determined by the average underlying price over some preset time period – see, e.g., [Rogers and Shi, 1995]), barrier options (which can be exercised only if the underlying security's price passes a certain level or "barrier" – see, e.g., [Haug, 2001]), other exotic options (a broad category of options that typically are complexly structured – see, e.g., [Fabozzi, 2002]), etc. Let us also mention binary (a.k.a. all-or-nothing or digital) options (that pay a preset amount, say, \$1, if the underlying security meets a predefined condition on expiration, otherwise they simply expire without paying anything to the holder – see, e.g., [Breeden and Litzenberger, 1978]).

Some trading strategies can be built using, e.g., combinations of options. Such trading strategies can be divided into two groups: directional and non-directional.

Directional strategies imply an expectation on the direction of the future stock price movements. Non-directional (a.k.a. neutral) strategies are not based on the future direction: the trader is oblivious to whether the stock price goes up or down.

Directional strategies can be divided into two subgroups: (i) bullish strategies, where the trader profits if the stock price goes up; and (ii) bearish strategies, where the trader profits if the stock price goes down. Non-directional strategies can be divided into two subgroups: (a) volatility strategies that profit if the stock has large price movements (high volatility environment); and (b) sideways strategies that profit if the stock price remains stable (low volatility environment). Also, one can distinguish income, capital gain, hedging strategies, etc. (see, e.g., [Cohen, 2005]).

In the remainder of this section, unless stated otherwise, all options are for the same stock and have the same time-to-maturity (TTM). The moneyness abbreviations are: ATM = at-the-money, ITM = in-the-money, OTM = out-of-the-money. Also: f_T is the payoff at maturity T; S_0 is the stock price at the time $t = 0$ of entering the trade (i.e., establishing the initial position); S_T is the stock price at maturity; C is the net credit received at $t = 0$, and D is the net debit required at $t = 0$, as applicable; $H = D$ (for a net debit trade) or $H = -C$ (for a net credit trade);[8] S_{*up} and S_{*down} are the higher and lower break-even (i.e., for which $f_T = 0$) stock prices at maturity; if there is only one break-even price, it is denoted by S_*; P_{max} is the maximum profit at maturity; L_{max} is the maximum loss at maturity.

2.2 Strategy: Covered call

This strategy (a.k.a. "buy-write" strategy) amounts to buying stock and writing a call option with a strike price K against the stock position. The trader's outlook on the stock price is neutral to bullish. The covered call strategy has the same payoff as writing a put option (short/naked put).[9] While maintaining the long stock position, the trader can generate income by periodically selling OTM call options. We have:[10]

$$f_T = S_T - S_0 - (S_T - K)^+ + C = K - S_0 - (K - S_T)^+ + C \tag{1}$$
$$S_* = S_0 - C \tag{2}$$
$$P_{max} = K - S_0 + C \tag{3}$$
$$L_{max} = S_0 - C \tag{4}$$

2.3 Strategy: Covered put

This strategy (a.k.a. "sell-write" strategy) amounts to shorting stock and writing a put option with a strike price K against the stock position. The trader's outlook is

[8] H is the net debit for all bought option premia less the net credit for all sold option premia.
[9] This is related to put-call parity (see, e.g., [Stoll, 1969], [Hull, 2012]).
[10] For some literature on covered call strategies, see, e.g., [Pounds, 1978], [Whaley, 2002], [Feldman and Roy, 2004], [Hill *et al*, 2006], [Kapadia and Szado, 2007], [Che and Fung, 2011], [Mugwagwa *et al*, 2012], [Israelov and Nielsen, 2014], [Israelov and Nielsen, 2015a], [Hemler and Miller, 2015].

neutral to bearish. The covered put strategy has the same payoff as writing a call option (short/naked call). While maintaining the short stock position, the trader can generate income by periodically selling OTM put options. We have:[11]

$$f_T = S_0 - S_T - (K - S_T)^+ + C = S_0 - K - (S_T - K)^+ + C \tag{5}$$
$$S_* = S_0 + C \tag{6}$$
$$P_{max} = S_0 - K + C \tag{7}$$
$$L_{max} = \text{unlimited} \tag{8}$$

2.4 Strategy: Protective put

This strategy (a.k.a. "married put" or "synthetic call") amounts to buying stock and an ATM or OTM put option with a strike price $K \leq S_0$. The trader's outlook is bullish. This is a hedging strategy: the put option hedges the risk of the stock price falling. We have:[12]

$$f_T = S_T - S_0 + (K - S_T)^+ - D = K - S_0 + (S_T - K)^+ - D \tag{9}$$
$$S_* = S_0 + D \tag{10}$$
$$P_{max} = \text{unlimited} \tag{11}$$
$$L_{max} = S_0 - K + D \tag{12}$$

2.5 Strategy: Protective call

This strategy (a.k.a. "married call" or "synthetic put") amounts to shorting stock and buying an ATM or OTM call option with a strike price $K \geq S_0$. The trader's outlook is bearish. This is a hedging strategy: the call option hedges the risk of the stock price rising. We have:[13]

$$f_T = S_0 - S_T + (S_T - K)^+ - D = S_0 - K + (K - S_T)^+ - D \tag{13}$$
$$S_* = S_0 - D \tag{14}$$
$$P_{max} = S_0 - D \tag{15}$$
$$L_{max} = K - S_0 + D \tag{16}$$

2.6 Strategy: Bull call spread

This is a vertical spread consisting of a long position in a close to ATM call option with a strike price K_1, and a short position in an OTM call option with a higher

[11] The covered put option strategy is symmetrical to the covered call option strategy. Academic literature on the covered put option strategy appears to be scarce. See, e.g., [Che, 2016].

[12] For some literature on protective put strategies, see, e.g., [Figlewski, Chidambaran and Kaplan, 1993], [Israelov and Nielsen, 2015b], [Israelov, Nielsen and Villalon, 2017], [Israelov, 2017].

[13] The protective call option strategy is symmetrical to the protective put option strategy. Academic literature on the protective call option strategy appears to be scarce. See, e.g., [Jabbour and Budwick, 2010], [Tokic, 2013].

strike price K_2. This is a net debit trade. The trader's outlook is bullish: the strategy profits if the stock price rises. This is a capital gain strategy. We have:[14]

$$f_T = (S_T - K_1)^+ - (S_T - K_2)^+ - D \tag{17}$$
$$S_* = K_1 + D \tag{18}$$
$$P_{max} = K_2 - K_1 - D \tag{19}$$
$$L_{max} = D \tag{20}$$

2.7 Strategy: Bull put spread

This is a vertical spread consisting of a long position in an OTM put option with a strike price K_1, and a short position in another OTM put option with a higher strike price K_2. This is a net credit trade. The trader's outlook is bullish. This is an income strategy. We have:

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ + C \tag{21}$$
$$S_* = K_2 - C \tag{22}$$
$$P_{max} = C \tag{23}$$
$$L_{max} = K_2 - K_1 - C \tag{24}$$

2.8 Strategy: Bear call spread

This is a vertical spread consisting of a long position in an OTM call option with a strike price K_1, and a short position in another OTM call option with a lower strike price K_2. This is a net credit trade. The trader's outlook is bearish. This is an income strategy. We have:

$$f_T = (S_T - K_1)^+ - (S_T - K_2)^+ + C \tag{25}$$
$$S_* = K_2 + C \tag{26}$$
$$P_{max} = C \tag{27}$$
$$L_{max} = K_1 - K_2 - C \tag{28}$$

2.9 Strategy: Bear put spread

This is a vertical spread consisting of a long position in a close to ATM put option with a strike price K_1, and a short position in an OTM put option with a lower

[14] For some literature on bull/bear call/put vertical spreads, see, e.g., [Cartea and Pedraz, 2012], [Chaput and Ederington, 2003], [Chaput and Ederington, 2005], [Chen, Chen and Howell, 1999], [Cong, Tan and Weng, 2013], [Cong, Tan and Weng, 2014], [Matsypura and Timkovsky, 2010], [Shah, 2017], [Wong, Thompson and Teh, 2011], [Zhang, 2015]. Also see [Clarke, de Silva and Thorley, 2013], [Cohen, 2005], [Jabbour and Budwick, 2010], [McMillan, 2002], [The Options Institute, 1995].

strike price K_2. This is a net debit trade. The trader's outlook is bearish: this strategy profits if the stock price falls. This is a capital gain strategy. We have:

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ - D \tag{29}$$
$$S_* = K_1 - D \tag{30}$$
$$P_{max} = K_1 - K_2 - D \tag{31}$$
$$L_{max} = D \tag{32}$$

2.10 Strategy: Long synthetic forward

This strategy amounts to buying an ATM call option and selling an ATM put option with a strike price $K = S_0$. This can be a net debit or net credit trade. Typically, $|H| \ll S_0$. The trader's outlook is bullish: this strategy mimics a long stock or futures position; it replicates a long forward contract with the delivery price K and the same maturity as the options. This is a capital gain strategy. We have:[15]

$$f_T = (S_T - K)^+ - (K - S_T)^+ - H = S_T - K - H \tag{33}$$
$$S_* = K + H \tag{34}$$
$$P_{max} = \text{unlimited} \tag{35}$$
$$L_{max} = K + H \tag{36}$$

2.11 Strategy: Short synthetic forward

This strategy amounts to buying an ATM put option and selling an ATM call option with a strike price $K = S_0$. This can be a net debit or net credit trade. Typically, $|H| \ll S_0$. The trader's outlook is bearish: this strategy mimics a short stock or futures position; it replicates a short forward contract with the delivery price K and the same maturity as the options. This is a capital gain strategy. We have:

$$f_T = (K - S_T)^+ - (S_T - K)^+ - H = K - S_T - H \tag{37}$$
$$S_* = K - H \tag{38}$$
$$P_{max} = K - H \tag{39}$$
$$L_{max} = \text{unlimited} \tag{40}$$

2.12 Strategy: Long combo

This strategy (a.k.a. "long risk reversal") amounts to buying an OTM call option with a strike price K_1 and selling an OTM put option with a strike price K_2. The

[15] For some literature on long/short synthetic forward contracts (a.k.a. synthetic futures), see, e.g., [Benavides, 2009], [Bozic and Fortenbery, 2012], [DeMaskey, 1995], [Ebrahim and Rahman, 2005], [Nandy and Chattopadhyay, 2016].

trader's outlook is bullish. This is a capital gain strategy.[16] We have ($K_1 > K_2$):

$$f_T = (S_T - K_1)^+ - (K_2 - S_T)^+ - H \tag{41}$$
$$S_* = K_1 + H, \quad H > 0 \tag{42}$$
$$S_* = K_2 + H, \quad H < 0 \tag{43}$$
$$K_2 \leq S_* \leq K_1, \quad H = 0 \tag{44}$$
$$P_{max} = \text{unlimited} \tag{45}$$
$$L_{max} = K_2 + H \tag{46}$$

2.13 Strategy: Short combo

This strategy (a.k.a. "short risk reversal") amounts to buying an OTM put option with a strike price K_1 and selling an OTM call option with a strike price K_2. The trader's outlook is bearish. This is a capital gain strategy. We have ($K_2 > K_1$):

$$f_T = (K_1 - S_T)^+ - (S_T - K_2)^+ - H \tag{47}$$
$$S_* = K_1 - H, \quad H > 0 \tag{48}$$
$$S_* = K_2 - H, \quad H < 0 \tag{49}$$
$$K_1 \leq S_* \leq K_2, \quad H = 0 \tag{50}$$
$$P_{max} = K_1 - H \tag{51}$$
$$L_{max} = \text{unlimited} \tag{52}$$

2.14 Strategy: Bull call ladder

This is a vertical spread consisting of a long position in (usually) a close to ATM call option with a strike price K_1, a short position in an OTM call option with a strike price K_2, and a short position in another OTM call option with a higher strike price K_3. A bull call ladder is a bull call spread financed by selling another OTM call option (with the strike price K_3).[17] This adjusts the trader's outlook from bullish (bull call spread) to conservatively bullish or even non-directional (with an expectation of low volatility). We have:

$$f_T = (S_T - K_1)^+ - (S_T - K_2)^+ - (S_T - K_3)^+ - H \tag{53}$$
$$S_{*down} = K_1 + H, \quad H > 0 \tag{54}$$
$$S_{*up} = K_3 + K_2 - K_1 - H \tag{55}$$
$$P_{max} = K_2 - K_1 - H \tag{56}$$
$$L_{max} = \text{unlimited} \tag{57}$$

[16] For some literature on long/short combo strategies, see, e.g., [Rusnáková, Šoltés and Szabo, 2015], [Šoltés, 2011], [Šoltés and Rusnáková, 2012]. Also see, e.g., [Chaput and Ederington, 2003].
[17] In this sense, this is an "income" strategy.

2.15 Strategy: Bull put ladder

This is a vertical spread consisting of a short position in (usually) a close to ATM put option with a strike price K_1, a long position in an OTM put option with a strike price K_2, and a long position in another OTM put option with a lower strike price K_3. A bull put ladder typically arises when a bull put spread (a bullish strategy) goes wrong (the stock trades lower), so the trader buys another OTM put option (with the strike price K_3) to adjust the position to bearish. We have:[18]

$$f_T = (K_3 - S_T)^+ + (K_2 - S_T)^+ - (K_1 - S_T)^+ - H \tag{58}$$
$$S_{*up} = K_1 + H, \quad H < 0 \tag{59}$$
$$S_{*down} = K_3 + K_2 - K_1 - H \tag{60}$$
$$P_{max} = K_3 + K_2 - K_1 - H \tag{61}$$
$$L_{max} = K_1 - K_2 + H \tag{62}$$

2.16 Strategy: Bear call ladder

This is a vertical spread consisting of a short position in (usually) a close to ATM call option with a strike price K_1, a long position in an OTM call option with a strike price K_2, and a long position in another OTM call option with a higher strike price K_3. A bear call ladder typically arises when a bear call spread (a bearish strategy) goes wrong (the stock trades higher), so the trader buys another OTM call option (with the strike price K_3) to adjust the position to bullish. We have:

$$f_T = (S_T - K_3)^+ + (S_T - K_2)^+ - (S_T - K_1)^+ - H \tag{63}$$
$$S_{*down} = K_1 - H, \quad H < 0 \tag{64}$$
$$S_{*up} = K_3 + K_2 - K_1 + H \tag{65}$$
$$P_{max} = \text{unlimited} \tag{66}$$
$$L_{max} = K_2 - K_1 + H \tag{67}$$

2.17 Strategy: Bear put ladder

This is a vertical spread consisting of a long position in (usually) a close to ATM put option with a strike price K_1, a short position in an OTM put option with a strike price K_2, and a short position in another OTM put option with a lower strike price K_3. A bear put ladder is a bear put spread financed by selling another OTM put option (with the strike price K_3).[19] This adjusts the trader's outlook from bearish (bear put spread) to conservatively bearish or even non-directional (with an

[18] For some literature on ladder strategies, see, e.g., [Amaitiek, Bálint and Rešovský, 2010], [Harčariková and Šoltés, 2016], [He, Tang and Zhang, 2016], [Šoltés and Amaitiek, 2010a].

[19] In this sense, as for the bull call ladder, this is an "income" strategy.

expectation of low volatility). We have (assuming $K_3 + K_2 - K_1 + H > \max(H, 0)$):

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ - (K_3 - S_T)^+ - H \tag{68}$$
$$S_{*up} = K_1 - H, \quad H > 0 \tag{69}$$
$$S_{*down} = K_3 + K_2 - K_1 + H \tag{70}$$
$$P_{max} = K_1 - K_2 - H \tag{71}$$
$$L_{max} = K_3 + K_2 - K_1 + H \tag{72}$$

2.18 Strategy: Calendar call spread

This is a horizontal spread consisting of a long position in a close to ATM call option with TTM T' and a short position in another call option with the same strike price K but shorter TTM $T < T'$. This is a net debit trade. The trader's outlook is neutral to bullish. At the expiration of the short call option ($t = T$), the best case scenario is if the stock price is right at the strike price ($S_T = K$). At $t = T$ let V be the value of the long call option (expiring at $t = T'$) assuming $S_T = K$. We have:[20]

$$P_{max} = V - D \tag{73}$$
$$L_{max} = D \tag{74}$$

If at the expiration of the short call option the stock price $S_{stop-loss} \leq S_T \leq K$, where $S_{stop-loss}$ is the stop-loss price below which the trader would unwind the entire position, then the trader can write another call option with the strike price K and TTM $T_1 < T'$. While maintaining the long position in the call option with TTM T', the trader can generate income by periodically selling call options with shorter maturities. In this regard, this strategy resembles the covered call strategy.

2.19 Strategy: Calendar put spread

This is a horizontal spread consisting of a long position in a close to ATM put option with TTM T' and a short position in another put option with the same strike price K but shorter TTM $T < T'$. This is a net debit trade. The trader's outlook is neutral to bearish. At the expiration of the short put option ($t = T$), the best case scenario is if the stock price is right at the strike price ($S_T = K$). At $t = T$ let V be the value of the long put option (expiring at $t = T'$) assuming $S_T = K$. We have:

$$P_{max} = V - D \tag{75}$$
$$L_{max} = D \tag{76}$$

If at the expiration of the short put option the stock price $K \leq S_T \leq S_{stop-loss}$, where $S_{stop-loss}$ is the stop-loss price above which the trader would unwind the

[20] For some literature on calendar/diagonal call/put spreads, see, e.g., [Carmona and Durrleman, 2003], [Carr and Javaheri, 2005], [Dale and Currie, 2015], [Gatheral and Jacquier, 2014], [Kawaller, Koch and Ludan, 2002], [Liu and Tang, 2010], [Manoliu, 2004], [Pirrong, 2017], [Till, 2008].

entire position, then the trader can write another put option with the strike price K and TTM $T_1 < T'$. While maintaining the long position in the put option with TTM T', the trader can generate income by periodically selling put options with shorter maturities. In this regard, this strategy resembles the covered put strategy.

2.20 Strategy: Diagonal call spread

This is a diagonal spread consisting of a long position in a deep ITM call option with a strike price K_1 and TTM T', and a short position in an OTM call option with a strike price K_2 and shorter TTM $T < T'$. This is a net debit trade. The trader's outlook is bullish. At $t = T$ let V be the value of the long call option (expiring at $t = T'$) assuming $S_T = K$. We have:

$$P_{max} = V - D \tag{77}$$
$$L_{max} = D \tag{78}$$

If at the expiration of the short call option the stock price $S_{stop-loss} \leq S_T \leq K_2$, where $S_{stop-loss}$ is the stop-loss price below which the trader would unwind the entire position, then the trader can write another OTM call option with TTM $T_1 < T'$. While maintaining the long position in the call option with TTM T', the trader can generate income by periodically selling OTM call options with shorter maturities. In this regard, this strategy is similar to the calendar call spread. The main difference is that, in the diagonal call spread the deep ITM call option (unlike the close to ATM call option in the calendar call spread) more closely mimics the underlying stock, so the position is more protected against a sharp rise in the stock price.

2.21 Strategy: Diagonal put spread

This is a diagonal spread consisting of a long position in a deep ITM put option with a strike price K_1 and TTM T', and a short position in an OTM put option with a strike price K_2 and shorter TTM $T < T'$. This is a net debit trade. The trader's outlook is bearish. At $t = T$ let V be the value of the long put option (expiring at $t = T'$) assuming $S_T = K$. We have:

$$P_{max} = V - D \tag{79}$$
$$L_{max} = D \tag{80}$$

If at the expiration of the short put option the stock price $K_2 \leq S_T \leq S_{stop-loss}$, where $S_{stop-loss}$ is the stop-loss price above which the trader would unwind the entire position, then the trader can write another OTM put option with TTM $T_1 < T'$. While maintaining the long position in the put option with TTM T', the trader can generate income by periodically selling OTM put options with shorter maturities. In this regard, this strategy is similar to the calendar put spread. The main difference is that, in the diagonal put spread the deep ITM put option (unlike the close to

ATM put option in the calendar put spread) more closely mimics the underlying stock, so the position is more protected against a sharp drop in the stock price.

2.22 Strategy: Long straddle

This is a volatility strategy consisting of a long position in an ATM call option, and a long position in an ATM put option with a strike price K. This is a net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have[21]:

$$f_T = (S_T - K)^+ + (K - S_T)^+ - D \tag{81}$$
$$S_{*up} = K + D \tag{82}$$
$$S_{*down} = K - D \tag{83}$$
$$P_{max} = \text{unlimited} \tag{84}$$
$$L_{max} = D \tag{85}$$

2.23 Strategy: Long strangle

This is a volatility strategy consisting of a long position in an OTM call option with a strike price K_1, and a long position in an OTM put option with a strike price K_2. This is a net debit trade. However, because both call and put options are OTM, this strategy is less costly to establish than a long straddle position. The flipside is that the movement in the stock price required to reach one of the break-even points is also more significant. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (S_T - K_1)^+ + (K_2 - S_T)^+ - D \tag{86}$$
$$S_{*up} = K_1 + D \tag{87}$$
$$S_{*down} = K_2 - D \tag{88}$$
$$P_{max} = \text{unlimited} \tag{89}$$
$$L_{max} = D \tag{90}$$

2.24 Strategy: Long guts

This is a volatility strategy consisting of a long position in an ITM call option with a strike price K_1, and a long position in an ITM put option with a strike price K_2. This is a net debit trade. Since both call and put options are ITM, this strategy

[21] For some literature on straddle/strangle strategies, see, e.g., [Copeland and Galai, 1983], [Coval and Shumway, 2001], [Engle and Rosenberg, 2000], [Gao, Xing and Zhang, 2017], [Goltz and Lai, 2009], [Guo, 2000], [Hansch, Naik and Viswanathan, 1998], [Noh, Engle and Kane, 1994], [Rusnáková and Šoltés, 2012], [Suresh, 2015]. Academic literature specifically on long/short guts strategies (which can be thought of as variations on straddles) appears to be more scarce. For a book reference, see, e.g., [Cohen, 2005]. For covered straddles, see, e.g., [Johnson, 1979].

is more costly to establish than a long straddle position. The trader's outlook is neutral. This is a capital gain strategy. We have (assuming $D > K_2 - K_1$):[22]

$$f_T = (S_T - K_1)^+ + (K_2 - S_T)^+ - D \tag{91}$$
$$S_{*up} = K_1 + D \tag{92}$$
$$S_{*down} = K_2 - D \tag{93}$$
$$P_{max} = \text{unlimited} \tag{94}$$
$$L_{max} = D - (K_2 - K_1) \tag{95}$$

2.25 Strategy: Short straddle

This a is sideways strategy consisting of a short position in an ATM call option, and a short position in an ATM put option with a strike price K. This is a net credit trade. The trader's outlook is neutral. This is an income strategy. We have:

$$f_T = -(S_T - K)^+ - (K - S_T)^+ + C \tag{96}$$
$$S_{*up} = K + C \tag{97}$$
$$S_{*down} = K - C \tag{98}$$
$$P_{max} = C \tag{99}$$
$$L_{max} = \text{unlimited} \tag{100}$$

2.26 Strategy: Short strangle

This is a sideways strategy consisting of a short position in an OTM call option with a strike price K_1, and a short position in an OTM put option with a strike price K_2. This is a net credit trade. Since both call and put options are OTM, this strategy is less risky than a short straddle position. The flipside is that the initial credit is also lower. The trader's outlook is neutral. This is an income strategy. We have:

$$f_T = -(S_T - K_1)^+ - (K_2 - S_T)^+ + C \tag{101}$$
$$S_{*up} = K_1 + C \tag{102}$$
$$S_{*down} = K_2 - C \tag{103}$$
$$P_{max} = C \tag{104}$$
$$L_{max} = \text{unlimited} \tag{105}$$

2.27 Strategy: Short guts

This is a sideways strategy consisting of a short position in an ITM call option with a strike price K_1, and a short position in an ITM put option with a strike price K_2. This is a net credit trade. Since both call and put options are ITM, the initial

[22] Otherwise this strategy would generate risk-free profits.

credit is higher than in a short straddle position. The flipside is that the risk is also higher. The trader's outlook is neutral. This is an income strategy. We have:[23]

$$f_T = -(S_T - K_1)^+ - (K_2 - S_T)^+ + C \tag{106}$$
$$S_{*up} = K_1 + C \tag{107}$$
$$S_{*down} = K_2 - C \tag{108}$$
$$P_{max} = C - (K_2 - K_1) \tag{109}$$
$$L_{max} = \text{unlimited} \tag{110}$$

2.28 Strategy: Long call synthetic straddle

This volatility strategy (which is the same as a long straddle with the put replaced by a synthetic put) amounts to shorting stock and buying *two* ATM (or the nearest ITM) call options with a strike price K. The trader's outlook is neutral. This is a capital gain strategy.[24] We have (assuming $S_0 \geq K$ and $D > S_0 - K$):

$$f_T = S_0 - S_T + 2 \times (S_T - K)^+ - D \tag{111}$$
$$S_{*up} = 2 \times K - S_0 + D \tag{112}$$
$$S_{*down} = S_0 - D \tag{113}$$
$$P_{max} = \text{unlimited} \tag{114}$$
$$L_{max} = D - (S_0 - K) \tag{115}$$

2.29 Strategy: Long put synthetic straddle

This volatility strategy (which is the same as a long straddle with the call replaced by a synthetic call) amounts to buying stock and buying *two* ATM (or the nearest ITM) put options with a strike price K. The trader's outlook is neutral. This is a capital gain strategy. We have (assuming $S_0 \leq K$ and $D > K - S_0$):

$$f_T = S_T - S_0 + 2 \times (K - S_T)^+ - D \tag{116}$$
$$S_{*up} = S_0 + D \tag{117}$$
$$S_{*down} = 2 \times K - S_0 - D \tag{118}$$
$$P_{max} = \text{unlimited} \tag{119}$$
$$L_{max} = D - (K - S_0) \tag{120}$$

2.30 Strategy: Short call synthetic straddle

This sideways strategy (which is the same as a short straddle with the put replaced by a synthetic put) amounts to buying stock and selling *two* ATM (or the nearest

[23] Similarly to long guts, here we assume that $C > K_2 - K_1$.

[24] Academic literature on synthetic straddles appears to be scarce. See, e.g., [Trifonov *et al*, 2011], [Trifonov *et al*, 2014].

OTM) call options with a strike price K. The trader's outlook is neutral. This is a capital gain strategy. We have (assuming $S_0 \leq K$):

$$f_T = S_T - S_0 - 2 \times (S_T - K)^+ + C \tag{121}$$
$$S_{*up} = 2 \times K - S_0 + C \tag{122}$$
$$S_{*down} = S_0 - C \tag{123}$$
$$P_{max} = K - S_0 + C \tag{124}$$
$$L_{max} = \text{unlimited} \tag{125}$$

2.31 Strategy: Short put synthetic straddle

This sideways strategy (which is the same as a short straddle with the call replaced by a synthetic call) amounts to shorting stock and selling *two* ATM (or the nearest OTM) put options with a strike price K. The trader's outlook is neutral. This is a capital gain strategy. We have (assuming $S_0 \geq K$):

$$f_T = S_0 - S_T - 2 \times (K - S_T)^+ + C \tag{126}$$
$$S_{*up} = S_0 + C \tag{127}$$
$$S_{*down} = 2 \times K - S_0 - C \tag{128}$$
$$P_{max} = S_0 - K + C \tag{129}$$
$$L_{max} = \text{unlimited} \tag{130}$$

2.32 Strategy: Covered short straddle

This strategy amounts to augmenting a covered call by writing a put option with the same strike price K and TTM as the sold call option and thereby increasing the income. The trader's outlook is bullish. We have:

$$f_T = S_T - S_0 - (S_T - K)^+ - (K - S_T)^+ + C \tag{131}$$
$$S_* = \frac{1}{2}\,(S_0 + K - C) \tag{132}$$
$$P_{max} = K - S_0 + C \tag{133}$$
$$L_{max} = S_0 + K - C \tag{134}$$

2.33 Strategy: Covered short strangle

This strategy amounts to augmenting a covered call by writing an OTM put option with a strike price K' and the same TTM as the sold call option (whose strike price is K) and thereby increasing the income. The trader's outlook is bullish. We have:

$$f_T = S_T - S_0 - (S_T - K)^+ - (K' - S_T)^+ + C \tag{135}$$
$$P_{max} = K - S_0 + C \tag{136}$$
$$L_{max} = S_0 + K' - C \tag{137}$$

2.34 Strategy: Strap

This is a volatility strategy consisting of a long position in *two* ATM call options, and a long position in an ATM put option with a strike price K. This is a net debit trade. The trader's outlook is bullish. This is a capital gain strategy. We have:[25]

$$f_T = 2 \times (S_T - K)^+ + (K - S_T)^+ - D \tag{138}$$
$$S_{*up} = K + \frac{D}{2} \tag{139}$$
$$S_{*down} = K - D \tag{140}$$
$$P_{max} = \text{unlimited} \tag{141}$$
$$L_{max} = D \tag{142}$$

2.35 Strategy: Strip

This is a volatility strategy consisting of a long position in an ATM call option, and a long position in *two* ATM put options with a strike price K. This is a net debit trade. The trader's outlook is bearish. This is a capital gain strategy. We have:

$$f_T = (S_T - K)^+ + 2 \times (K - S_T)^+ - D \tag{143}$$
$$S_{*up} = K + D \tag{144}$$
$$S_{*down} = K - \frac{D}{2} \tag{145}$$
$$P_{max} = \text{unlimited} \tag{146}$$
$$L_{max} = D \tag{147}$$

2.36 Strategy: Call ratio backspread

This strategy consists of a short position in N_S close to ATM call options with a strike price K_1, and a long position in N_L OTM call options with a strike price K_2, where $N_L > N_S$. Typically, $N_L = 2$ and $N_S = 1$, or $N_L = 3$ and $N_S = 2$. The trader's outlook is strongly bullish. This is a capital gain strategy. We have:[26]

$$f_T = N_L \times (S_T - K_2)^+ - N_S \times (S_T - K_1)^+ - H \tag{148}$$
$$S_{*down} = K_1 - H/N_S, \quad H < 0 \tag{149}$$
$$S_{*up} = (N_L \times K_2 - N_S \times K_1 + H)/(N_L - N_S) \tag{150}$$
$$P_{max} = \text{unlimited} \tag{151}$$
$$L_{max} = N_S \times (K_2 - K_1) + H \tag{152}$$

[25] For some literature on strip and strap strategies, see, e.g., [Jha and Kalimipal, 2010], [Topaloglou, Vladimirou and Zenios, 2011].

[26] For some literature on call/put ratio (back)spreads, see, e.g., [Augustin, Brenner and Subrahmanyam, 2015], [Chaput and Ederington, 2008], [Šoltés, 2010], [Šoltés and Amaitiek, 2010b], [Šoltés and Rusnáková, 2013].

2.37 Strategy: Put ratio backspread

This strategy consists of a short position in N_S close to ATM put options with a strike price K_1, and a long position in N_L OTM put options with a strike price K_2, where $N_L > N_S$. Typically, $N_L = 2$ and $N_S = 1$, or $N_L = 3$ and $N_S = 2$. The trader's outlook is strongly bearish. This is a capital gain strategy. We have:

$$f_T = N_L \times (K_2 - S_T)^+ - N_S \times (K_1 - S_T)^+ - H \tag{153}$$
$$S_{*up} = K_1 + H/N_S, \quad H < 0 \tag{154}$$
$$S_{*down} = (N_L \times K_2 - N_S \times K_1 - H)/(N_L - N_S) \tag{155}$$
$$P_{max} = N_L \times K_2 - N_S \times K_1 - H \tag{156}$$
$$L_{max} = N_S \times (K_1 - K_2) + H \tag{157}$$

2.38 Strategy: Ratio call spread

This strategy consists of a short position in N_S close to ATM call options with a strike price K_1, and a long position in N_L ITM call options with a strike price K_2, where $N_L < N_S$. Typically, $N_L = 1$ and $N_S = 2$, or $N_L = 2$ and $N_S = 3$. This is an income strategy if it is structured as a net credit trade. The trader's outlook is neutral to bearish. We have:[27]

$$f_T = N_L \times (S_T - K_2)^+ - N_S \times (S_T - K_1)^+ - H \tag{158}$$
$$S_{*down} = K_2 + H/N_L, \quad H > 0 \tag{159}$$
$$S_{*up} = (N_S \times K_1 - N_L \times K_2 - H)/(N_S - N_L) \tag{160}$$
$$P_{max} = N_L \times (K_1 - K_2) - H \tag{161}$$
$$L_{max} = \text{unlimited} \tag{162}$$

2.39 Strategy: Ratio put spread

This strategy consists of a short position in N_S close to ATM put options with a strike price K_1, and a long position in N_L ITM put options with a strike price K_2, where $N_L < N_S$. Typically, $N_L = 1$ and $N_S = 2$, or $N_L = 2$ and $N_S = 3$. This is an income strategy if it is structured as a net credit trade. The trader's outlook is neutral to bullish. We have:

$$f_T = N_L \times (K_2 - S_T)^+ - N_S \times (K_1 - S_T)^+ - H \tag{163}$$
$$S_{*up} = K_2 - H/N_L, \quad H > 0 \tag{164}$$
$$S_{*down} = (N_S \times K_1 - N_L \times K_2 + H)/(N_S - N_L) \tag{165}$$
$$P_{max} = N_L \times (K_2 - K_1) - H \tag{166}$$
$$L_{max} = N_S \times K_1 - N_L \times K_2 + H \tag{167}$$

[27] So, the difference between call/put ratio backspreads and ratio call/put spreads is that in the former $N_L > N_S$, while in the latter $N_L < N_S$.

2.40 Strategy: Long call butterfly

This is a sideways strategy consisting of a long position in an OTM call option with a strike price K_1, a short position in *two* ATM call options with a strike price K_2, and a long position in an ITM call option with a strike price K_3. The strikes are equidistant: $K_2 - K_3 = K_1 - K_2 = \kappa$. This is a relatively low cost net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:[28]

$$f_T = (S_T - K_1)^+ + (S_T - K_3)^+ - 2 \times (S_T - K_2)^+ - D \tag{168}$$
$$S_{*down} = K_3 + D \tag{169}$$
$$S_{*up} = K_1 - D \tag{170}$$
$$P_{max} = \kappa - D \tag{171}$$
$$L_{max} = D \tag{172}$$

2.40.1 Strategy: Modified call butterfly

This is a variation of the long call butterfly strategy where the strikes are no longer equidistant; instead we have $K_1 - K_2 < K_2 - K_3$. This results in a sideways strategy with a bullish bias. We have:

$$f_T = (S_T - K_1)^+ + (S_T - K_3)^+ - 2 \times (S_T - K_2)^+ - D \tag{173}$$
$$S_* = K_3 + D \tag{174}$$
$$P_{max} = K_2 - K_3 - D \tag{175}$$
$$L_{max} = D \tag{176}$$

2.41 Strategy: Long put butterfly

This is a sideways strategy consisting of a long position in an OTM put option with a strike price K_1, a short position in *two* ATM put options with a strike price K_2, and a long position in an ITM put option with a strike price K_3. The strikes are equidistant: $K_3 - K_2 = K_2 - K_1 = \kappa$. This is a relatively low cost net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (K_1 - S_T)^+ + (K_3 - S_T)^+ - 2 \times (K_2 - S_T)^+ - D \tag{177}$$
$$S_{*up} = K_3 - D \tag{178}$$
$$S_{*down} = K_1 + D \tag{179}$$
$$P_{max} = \kappa - D \tag{180}$$
$$L_{max} = D \tag{181}$$

[28] For some literature on butterfly spreads (including iron butterflies), see, e.g., [Balbás, Longarela and Lucia, 1999], [Howison, Reisinger and Witte, 2013], [Jongadsayakul, 2017], [Matsypura and Timkovsky, 2010], [Youbi, Pindza and Maré, 2017], [Wolf, 2014], [Wystup, 2017]. Academic literature on condor strategies (which can be thought of as variations on butterflies) appears to be more scarce. See, e.g., [Niblock, 2017].

2.41.1 Strategy: Modified put butterfly

This is a variation of the long put butterfly strategy where the strikes are no longer equidistant; instead we have $K_3-K_2 < K_2-K_1$. This results in a sideways strategy with a bullish bias. We have (for $H > 0$ there is also $S_{*up} = K_3 - H$):[29]

$$f_T = (K_1 - S_T)^+ + (K_3 - S_T)^+ - 2 \times (K_2 - S_T)^+ - H \tag{182}$$
$$S_{*down} = 2 \times K_2 - K_3 + H \tag{183}$$
$$P_{max} = K_3 - K_2 - H \tag{184}$$
$$L_{max} = 2 \times K_2 - K_1 - K_3 + H \tag{185}$$

2.42 Strategy: Short call butterfly

This is a volatility strategy consisting of a short position in an ITM call option with a strike price K_1, a long position in *two* ATM call options with a strike price K_2, and a short position in an OTM call option with a strike price K_3. The strikes are equidistant: $K_3 - K_2 = K_2 - K_1 = \kappa$. This is a net credit trade. In this sense, this is an income strategy. However, the potential reward is sizably smaller than with a short straddle or a short strangle (albeit with a lower risk). The trader's outlook is neutral. We have:

$$f_T = 2 \times (S_T - K_2)^+ - (S_T - K_1)^+ - (S_T - K_3)^+ + C \tag{186}$$
$$S_{*up} = K_3 - C \tag{187}$$
$$S_{*down} = K_1 + C \tag{188}$$
$$P_{max} = C \tag{189}$$
$$L_{max} = \kappa - C \tag{190}$$

2.43 Strategy: Short put butterfly

This is a volatility strategy consisting of a short position in an ITM put option with a strike price K_1, a long position in *two* ATM put options with a strike price K_2, and a short position in an OTM put option with a strike price K_3. The strikes are equidistant: $K_2 - K_3 = K_1 - K_2 = \kappa$. This is a net credit trade. In this sense, this is an income strategy. However, the potential reward is sizably smaller than with a short straddle or a short strangle (albeit with a lower risk). The trader's outlook is neutral. We have:

$$f_T = 2 \times (K_2 - S_T)^+ - (K_1 - S_T)^+ - (K_3 - S_T)^+ + C \tag{191}$$
$$S_{*down} = K_3 + C \tag{192}$$
$$S_{*up} = K_1 - C \tag{193}$$
$$P_{max} = C \tag{194}$$
$$L_{max} = \kappa - C \tag{195}$$

[29] Ideally, this should be structured as a net credit trade, albeit this may not always be possible.

2.44 Strategy: "Long" iron butterfly

This sideways strategy is a combination of a bull put spread and a bear call spread and consists of a long position in an OTM put option with a strike price K_1, a short position in an ATM put option and an ATM call option with a strike price K_2, and a long position in an OTM call option with a strike price K_3. The strikes are equidistant: $K_2 - K_1 = K_3 - K_2 = \kappa$. This is a net credit trade. The trader's outlook is neutral. This is an income strategy. We have:

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ - (S_T - K_2)^+ + (S_T - K_3)^+ + C \tag{196}$$
$$S_{*up} = K_2 + C \tag{197}$$
$$S_{*down} = K_2 - C \tag{198}$$
$$P_{max} = C \tag{199}$$
$$L_{max} = \kappa - C \tag{200}$$

2.45 Strategy: "Short" iron butterfly

This volatility strategy is a combination of a bear put spread and a bull call spread and consists of a short position in an OTM put option with a strike price K_1, a long position in an ATM put option and an ATM call option with a strike price K_2, and a short position in an OTM call option with a strike price K_3. The strikes are equidistant: $K_2 - K_1 = K_3 - K_2 = \kappa$. This is a net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (K_2 - S_T)^+ + (S_T - K_2)^+ - (K_1 - S_T)^+ - (S_T - K_3)^+ - D \tag{201}$$
$$S_{*up} = K_2 + D \tag{202}$$
$$S_{*down} = K_2 - D \tag{203}$$
$$P_{max} = \kappa - D \tag{204}$$
$$L_{max} = D \tag{205}$$

2.46 Strategy: Long call condor

This is a sideways strategy consisting of a long position in an ITM call option with a strike price K_1, a short position in an ITM call option with a higher strike price K_2, a short position in an OTM call option with a strike price K_3, and a long position in an OTM call option with a higher strike price K_4. All strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a relatively low cost net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (S_T - K_1)^+ - (S_T - K_2)^+ - (S_T - K_3)^+ + (S_T - K_4)^+ - D \tag{206}$$
$$S_{*up} = K_4 - D \tag{207}$$
$$S_{*down} = K_1 + D \tag{208}$$

$$P_{max} = \kappa - D \tag{209}$$
$$L_{max} = D \tag{210}$$

2.47 Strategy: Long put condor

This is a sideways strategy consisting of a long position in an OTM put option with a strike price K_1, a short position in an OTM put option with a higher strike price K_2, a short position in an ITM put option with a strike price K_3, and a long position in an ITM put option with a higher strike price K_4. All strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a relatively low cost net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ - (K_3 - S_T)^+ + (K_4 - S_T)^+ - D \tag{211}$$
$$S_{*up} = K_4 - D \tag{212}$$
$$S_{*down} = K_1 + D \tag{213}$$
$$P_{max} = \kappa - D \tag{214}$$
$$L_{max} = D \tag{215}$$

2.48 Strategy: Short call condor

This is a volatility strategy consisting of a short position in an ITM call option with a strike price K_1, a long position in an ITM call option with a higher strike price K_2, a long position in an OTM call option with a strike price K_3, and a short position in an OTM call option with a higher strike price K_4. All strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a relatively low net credit trade. As with a short call butterfly, the potential reward is sizably smaller than with a short straddle or a short strangle (albeit with a lower risk). So, this is a capital gain (rather than an income) strategy. The trader's outlook is neutral. We have:

$$f_T = (S_T - K_2)^+ + (S_T - K_3)^+ - (S_T - K_1)^+ - (S_T - K_4)^+ + C \tag{216}$$
$$S_{*up} = K_4 - C \tag{217}$$
$$S_{*down} = K_1 + C \tag{218}$$
$$P_{max} = C \tag{219}$$
$$L_{max} = \kappa - C \tag{220}$$

2.49 Strategy: Short put condor

This is a volatility strategy consisting of a short position in an OTM put option with a strike price K_1, a long position in an OTM put option with a higher strike price K_2, a long position in an ITM put option with a strike price K_3, and a short position in an ITM put option with a higher strike price K_4. All strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a relatively low net credit trade.

As with a short put butterfly, the potential reward is sizably smaller than with a short straddle or a short strangle (albeit with a lower risk). So, this is a capital gain (rather than an income) strategy. The trader's outlook is neutral. We have:

$$f_T = (K_2 - S_T)^+ + (K_3 - S_T)^+ - (K_1 - S_T)^+ - (K_4 - S_T)^+ + C \tag{221}$$
$$S_{*up} = K_4 - C \tag{222}$$
$$S_{*down} = K_1 + C \tag{223}$$
$$P_{max} = C \tag{224}$$
$$L_{max} = \kappa - C \tag{225}$$

2.50 Strategy: Long iron condor

This sideways strategy is a combination of a bull put spread and a bear call spread and consists of a long position in an OTM put option with a strike price K_1, a short position in an OTM put option with a higher strike price K_2, a short position in an OTM call option with a strike price K_3, and a long position in an OTM call option with a higher strike price K_4. The strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a net credit trade. The trader's outlook is neutral. This is an income strategy. We have:

$$f_T = (K_1 - S_T)^+ + (S_T - K_4)^+ - (K_2 - S_T)^+ - (S_T - K_3)^+ + C \tag{226}$$
$$S_{*up} = K_3 + C \tag{227}$$
$$S_{*down} = K_2 - C \tag{228}$$
$$P_{max} = C \tag{229}$$
$$L_{max} = \kappa - C \tag{230}$$

2.51 Strategy: Short iron condor

This volatility strategy is a combination of a bear put spread and a bull call spread and consists of a short position in an OTM put option with a strike price K_1, a long position in an OTM put option with a higher strike price K_2, a long position in an OTM call option with a strike price K_3, and a short position in an OTM call option with a higher strike price K_4. The strikes are equidistant: $K_4 - K_3 = K_3 - K_2 = K_2 - K_1 = \kappa$. This is a net debit trade. The trader's outlook is neutral. This is a capital gain strategy. We have:

$$f_T = (K_2 - S_T)^+ + (S_T - K_3)^+ - (K_1 - S_T)^+ - (S_T - K_4)^+ - D \tag{231}$$
$$S_{*up} = K_3 + D \tag{232}$$
$$S_{*down} = K_2 - D \tag{233}$$
$$P_{max} = \kappa - D \tag{234}$$
$$L_{max} = D \tag{235}$$

2.52 Strategy: Long box

This volatility strategy can be viewed as a combination of a long synthetic forward and a short synthetic forward, or as a combination of a bull call spread and a bear put spread, and consists of a long position in an ITM put option with a strike price K_1, a short position in an OTM put option with a lower strike price K_2, a long position in an ITM call option with the strike price K_2, and a short position in an OTM call option with the strike price K_1. The trader's outlook is neutral. This is a capital gain strategy.[30] We have (assuming $K_1 \geq K_2 + D$):

$$\begin{aligned} f_T &= (K_1 - S_T)^+ - (K_2 - S_T)^+ + (S_T - K_2)^+ - (S_T - K_1)^+ - D \\ &= K_1 - K_2 - D \qquad (236) \\ P_{max} &= (K_1 - K_2) - D \qquad (237) \end{aligned}$$

2.53 Strategy: Collar

This strategy (a.k.a. "fence") is a covered call augmented by a long put option as insurance against the stock price falling.[31] It amounts to buying stock, buying an OTM put option with a strike price K_1, and selling an OTM call option with a higher strike price K_2. The trader's outlook is moderately bullish. This is a capital gain strategy. We have:[32]

$$f_T = S_T - S_0 + (K_1 - S_T)^+ - (S_T - K_2)^+ - H \qquad (238)$$
$$S_* = S_0 + H \qquad (239)$$
$$P_{max} = K_2 - S_0 - H \qquad (240)$$
$$L_{max} = S_0 - K_1 + H \qquad (241)$$

2.54 Strategy: Bullish short seagull spread

This option trading strategy is a bull call spread financed with a sale of an OTM put option. It amounts to a short position in an OTM put option with a strike price K_1, a long position in an ATM call option with a strike price K_2, and a short position in an OTM call option with a strike price K_3. Ideally, the trade should be structured to have zero cost. The trader's outlook is bullish. This is a capital gain

[30] In some cases it can be used as a tax strategy – see, e.g., [Cohen, 2005]. For some literature on box option strategies, see, e.g., [BenZion, Anan and Yagil, 2005], [Bharadwaj and Wiggins, 2001], [Billingsley and Chance, 1985], [Clarke, de Silva and Thorley, 2013], [Fung, Mok and Wong, 2004], [Hemler and Miller, 1997], [Jongadsayakul, 2016], [Ronn and Ronn, 1989], [Vipul, 2009].

[31] Similarly, a short collar is a covered put augmented by a long call option.

[32] For some literature on collar strategies, see, e.g., [Bartonová, 2012], [Burnside *et al*, 2011], [D'Antonio, 2008], [Israelov and Klein, 2016], [Li and Yang, 2017], [Officer, 2004], [Officer, 2006], [Shan, Garvin and Kumar, 2010], [Szado and Schneeweis, 2010], [Szado and Schneeweis, 2011], [Timmermans, Schumacher and Ponds, 2017], [Yim *et al*, 2011].

strategy. We have:[33]

$$f_T = -(K_1 - S_T)^+ + (S_T - K_2)^+ - (S_T - K_3)^+ - H \tag{242}$$
$$S_* = K_2 + H, \quad H > 0 \tag{243}$$
$$S_* = K_1 + H, \quad H < 0 \tag{244}$$
$$K_1 \leq S_* \leq K_2, \quad H = 0 \tag{245}$$
$$P_{max} = K_3 - K_2 - H \tag{246}$$
$$L_{max} = K_1 + H \tag{247}$$

2.55 Strategy: Bearish long seagull spread

This option trading strategy is a short combo (short risk reversal) hedged against the stock price rising by buying an OTM call option. It amounts to a long position in an OTM put option with a strike price K_1, a short position in an ATM call option with a strike price K_2, and a long position in an OTM call option with a strike price K_3. Ideally, the trade should be structured to have zero cost. The trader's outlook is bearish. This is a capital gain strategy. We have:

$$f_T = (K_1 - S_T)^+ - (S_T - K_2)^+ + (S_T - K_3)^+ - H \tag{248}$$
$$S_* = K_1 - H, \quad H > 0 \tag{249}$$
$$S_* = K_2 - H, \quad H < 0 \tag{250}$$
$$K_1 \leq S_* \leq K_2, \quad H = 0 \tag{251}$$
$$P_{max} = K_1 - H \tag{252}$$
$$L_{max} = K_3 - K_2 + H \tag{253}$$

2.56 Strategy: Bearish short seagull spread

This option trading strategy is a bear put spread financed with a sale of an OTM call option. It amounts to a short position in an OTM put option with a strike price K_1, a long position in an ATM put option with a strike price K_2, and a short position in an OTM call option with a strike price K_3. Ideally, the trade should be structured to have zero cost. The trader's outlook is bearish. This is a capital gain strategy. We have:

$$f_T = -(K_1 - S_T)^+ + (K_2 - S_T)^+ - (S_T - K_3)^+ - H \tag{254}$$
$$S_* = K_2 - H, \quad H > 0 \tag{255}$$
$$S_* = K_3 - H, \quad H < 0 \tag{256}$$
$$K_2 \leq S_* \leq K_3, \quad H = 0 \tag{257}$$
$$P_{max} = K_2 - K_1 - H \tag{258}$$
$$L_{max} = \text{unlimited} \tag{259}$$

[33] Academic literature on seagull spreads appears to be scarce. For a book reference, see, e.g., [Wystup, 2017].

2.57 Strategy: Bullish long seagull spread

This option trading strategy is a long combo (long risk reversal) hedged against the stock price falling by buying an OTM put option. It amounts to a long position in an OTM put option with a strike price K_1, a short position in an ATM put option with a strike price K_2, and a long position in an OTM call option with a strike price K_3. Ideally, the trade should be structured to have zero cost. The trader's outlook is bullish. This is a capital gain strategy. We have:

$$f_T = (K_1 - S_T)^+ - (K_2 - S_T)^+ + (S_T - K_3)^+ - H \tag{260}$$

$$S_* = K_3 + H, \quad H > 0 \tag{261}$$

$$S_* = K_2 + H, \quad H < 0 \tag{262}$$

$$K_2 \leq S_* \leq K_3, \quad H = 0 \tag{263}$$

$$P_{max} = \text{unlimited} \tag{264}$$

$$L_{max} = K_2 - K_1 + H \tag{265}$$

A R Source Code for Backtesting

In this appendix we give the R (R Package for Statistical Computing, `http://www.r-project.org`) source code for backtesting intraday strategies, where the position is established at the open and liquidated at the close of the same day. The sole purpose of this code is to illustrate some simple tricks for doing out-of-sample backtesting. In particular, this code does not deal with the survivorship bias in any way,[245] albeit for this kind of strategies – precisely because these are intraday strategies – the survivorship bias is not detrimental (see, e.g., [Kakushadze, 2015b]).[246]

The main function (which internally calls some subfunctions) is `qrm.backtest()` with the following inputs: (i) `days` is the lookback; (ii) `d.r` is used for computing risk, both as the length of the moving standard deviation `tr` (computed internally over `d.r`-day moving windows) as well as the lookback for computing the risk model (and, if applicable, a statistical industry classification) – see below; (iii) `d.addv` is used as the lookback for the average daily dollar volume `addv`, which is computed internally; (iv) `n.addv` is the number of top tickers by `addv` used as the trading universe, which is recomputed every `d.r` days; (v) `inv.lvl` is the total investment level (long plus short, and the strategy is dollar-neutral); (vi) `bnds` controls the position bounds (which are the same in this strategy as the trading bounds), i.e., the dollar holdings H_i for each stock are bounded via (B_i are the `bnds` elements, which can be uniform)

$$|H_i| \leq B_i \; A_i \tag{548}$$

where $i = 1, \ldots, N$ labels the stocks in the trading universe, and A_i are the corresponding elements of `addv`; (vii) `incl.cost` is a Boolean for including linear trading costs, which are modeled as follows.[247] For the stock labeled by i, let E_i be its expected return, and w_i be its weight in the portfolio. The source code below determines w_i via (mean-variance) optimization (with bounds). For the stock labeled by i, let the linear trading cost per *dollar* traded be τ_i. Including such costs in portfolio optimization amounts to replacing the expected return of the portfolio

$$E_{port} = \sum_{i=1}^{N} E_i \; w_i \tag{549}$$

by

$$E_{port} = \sum_{i=1}^{N} \left[E_i \; w_i - \tau_i \; |w_i|\right] \tag{550}$$

[245] I.e., simply put, it does not account for the fact that in the past there were tickers that are no longer there at present, be it due to bankruptcies, mergers, acquisitions, etc. Instead, the input data is taken for the tickers that exist on a given day by looking back, say, some number of years.

[246] For some literature related to the survivorship bias, which is important for longer-horizon strategies, see, e.g., [Amin and Kat, 2003], [Brown *et al*, 1992], [Bu and Lacey, 2007], [Carhart *et al*, 2002], [Davis, 1996], [Elton, Gruber and Blake, 1996b], [Garcia and Gould, 1993].

[247] Here we closely follow the discussion in Subsection 3.1 of [Kakushadze and Yu, 2018b].

A complete algorithm for including linear trading costs in mean-variance optimization is given in, e.g., [Kakushadze, 2015b]. However, for our purposes here the following simple "hack" suffices. We can define the effective return

$$E_i^{eff} = \text{sign}(E_i)\ \max(|E_i| - \tau_i, 0) \tag{551}$$

and simply set

$$E_{port} = \sum_{i=1}^{N} E_i^{eff}\ w_i \tag{552}$$

I.e., if the magnitude for the expected return for a given stock is less than the expected cost to be incurred, we set the expected return to zero, otherwise we reduce said magnitude by said cost. This way we can avoid a nontrivial iterative procedure (see, e.g., [Kakushadze, 2015b]), albeit this is only an approximation.

So, what should we use as τ_i in (551)? The model of [Almgren *et al*, 2005] is reasonable for our purposes here. Let H_i be the *dollar* amount traded for the stock labeled by i. Then for the linear trading costs we have

$$T_i = \zeta\ \sigma_i\ \frac{|H_i|}{A_i} \tag{553}$$

where σ_i is the historical volatility, A_i is the average daily dollar volume (ADDV), and ζ is an overall normalization constant we need to fix. However, above we work with weights w_i, not traded dollar amounts H_i. In our case of a purely intraday trading strategy discussed above, they are related simply via $H_i = I\ w_i$, where I is the total investment level (i.e., the total absolute dollar holdings of the portfolio after establishing it). Therefore, we have (note that $T_i = \tau_i\ |H_i| = \tau_i\ I\ |w_i|$)

$$\tau_i = \zeta\ \frac{\sigma_i}{A_i} \tag{554}$$

We will fix the overall normalization ζ via the following heuristic. We will (conservatively) assume that the average linear trading cost per dollar traded is 10 bps (1 bps = 1 basis point = 1/100 of 1%),[248] i.e., $\text{mean}(\tau_i) = 10^{-3}$ and $\zeta = 10^{-3}/\text{mean}(\sigma_i/A_i)$.

Next, internally the code sources price and volume data by reading it from tab-delimited files[249] `nrm.ret.txt` (overnight return internally referred to as `ret` – see below), `nrm.open.txt` (daily raw, unadjusted open price, internally referred to as `open`), `nrm.close.txt` (daily raw, unadjusted close price, internally referred to as `close`), `nrm.vol.txt` (daily raw, unadjusted volume, internally referred to as `vol`), `nrm.prc.txt` (daily close price fully adjusted for all splits and dividends, internally referred to as `prc`). The rows of `ret`, `open`, `close`, `vol` and `prc` correspond to the N tickers (index i). Let trading days be labeled by $t = 0, 1, 2, \ldots, T$, where $t = 0$ is the

[248] This amounts to assuming that, to establish an equally-weighted portfolio, it costs 10 bps.
[249] This specific code does not use high, low, VWAP (volume-weighted average price), intraday (e.g., minute-by-minute) prices, etc. However, it is straightforward to modify it such that it does.

most recent day. Then the columns of `open`, `close`, `vol` and `prc` correspond to the trading days $t = 1, 2, \ldots, T$, i.e., the value of t is the same as the value of the column index. On the other hand, the columns of `ret` correspond to the overnight close-to-open returns from the trading day t to the trading day $t - 1$. I.e., the first column of `ret` corresponds to the overnight close-to-open return from the trading day $t = 1$ to the trading day $t = 0$. Furthermore, `ret`, call it $R_i(t)$, where $t = 1, 2, \ldots, T$ labels the columns of `ret`, is computed as follows:

$$R_i(t) = \ln\left(\frac{P_i^{AO}(t-1)}{P_i^{AC}(t)}\right) \tag{555}$$

$$P_i^{AO}(t) = \gamma_i^{adj}(t)\ P_i^{O}(t) \tag{556}$$

$$\gamma_i^{adj}(t) = \frac{P_i^{AC}(t)}{P_i^{C}(t)} \tag{557}$$

Here: $P_i^O(t)$ is the raw open price (which is the corresponding element of `open` for $t = 1, 2, \ldots, T$); $P_i^C(t)$ is the raw close price (which is the corresponding element of `close` for $t = 1, 2, \ldots, T$); $P_i^{AC}(t)$ is the fully adjusted close price (which is the corresponding element of `prc` for $t = 1, 2, \ldots, T$); $\gamma_i^{adj}(t)$ is the adjustment factor, which is used for computing the fully adjusted open price $P_i^{AO}(t)$; so $R_i(t)$ is the overnight, close-to-open return based on fully adjusted prices. Note that the $t = 0$ prices required for computing $R_i(1)$ are *not* part of the matrices `open`, `close` and `prc`. Also, the code internally assumes that the matrices `ret`, `open`, `close`, `vol` and `prc` are all aligned, i.e., all tickers and dates are the same and in the same order in each of the 5 files `nrm.ret.txt` (note the labeling of the returns described above), `nrm.open.txt`, `nrm.close.txt`, `nrm.vol.txt` and `nrm.prc.txt`. The ordering of the tickers in these files is immaterial, so long as it is the same in all 5 files as the code is oblivious to this ordering. However, the dates must be ordered in the descending order, i.e., the first column corresponds to the most recent date, the second column corresponds to the date before it, etc. (here "date" corresponds to a trading day). Finally, note that the internal function `read.x()` reads these files with the parameter value `as.is = T`. This means that these files are in the "R-ready" tab-delimited format, with $N + 1$ tab-delimited lines. The lines 2 through $N + 1$ have $T + 1$ elements each, the first element being a ticker symbol (so the N ticker symbols comprise `dimnames(·)[[1]]` of the corresponding matrix, e.g., `open` for the open prices), and the other T elements being the T values (e.g., $P_i^O(t)$, $t = 1, \ldots, T$, for the open prices). However, the first line has only T elements, which are the labels of the trading days (so these comprise `dimnames(·)[[2]]` of the corresponding matrix, e.g., `open` for the open prices). Internal functions that use this input data, such as `calc.mv.avg()` (which computes simple moving averages) and `calc.mv.sd()` (which computes simple moving standard deviations) are simple and self-explanatory.

As mentioned above, the input parameter `d.r` is used for recomputing the trading universe every `d.r` trading days and also recomputing the risk models (see below) every `d.r` trading days. These computations are done 100% out-of-sample, i.e., the

data used in these computations is 100% in the past w.r.t. to the trading day on which the resultant quantities are used for (simulated) trading. This is accomplished in part by using the internal function `calc.ix()`. Note that the input data described above is structured and further used in such a way that the backtests are 100% out-of-sample. Here two conceptually different aspects must be distinguished. Thus, we have the expected returns and "the rest", the latter – which can be loosely referred to as "risk management" – being the universe selection, the risk model computation, etc., i.e., the machinery that gets us from the expected returns to the desired holdings (that is, the strategy positions). The risk management part must be 100% out-of-sample. In real life the expected returns are also 100% out-of-sample. However, in backtesting, while the expected returns cannot under any circumstances look into the future, they can sometimes be "borderline in-sample". Thus, consider a strategy that today trades on the overnight yesterday's-close-to-today's-open return. If we assume that the positions are established based on this return sometime after the open, then the backtest is out-of-sample by the "delay" time between the open and when the position is established. However, if we assume that the position is established at the open, then this is the so-called "delay-0" strategy, and the backtest is "borderline in-sample" in the sense that in real life the orders would have to be sent with some, albeit possibly small, delay, but could never be executed exactly at the open. In this sense it still makes sense to backtest such a strategy to measure the strength of the signal. What would make no sense and should never be done is to run an outright in-sample backtest that looks into the future. E.g., using today's closing prices for computing expected returns for trading at today's open would be grossly in-sample. On the other hand, using yesterday's prices to trade at today's open is the so-called "delay-1" strategy, which is basically 1 day out-of-sample (and, not surprisingly, is expected to backtest much worse than a delay-0 strategy). The code gives examples of both delay-0 (mean-reversion) and delay-1 (momentum) strategies (see the comments `DELAY-0` and `DELAY-1` in the code).

The code internally computes the desired holdings via optimization. The optimizer function (which incorporates bounds and linear constraints such as dollar-neutrality) `bopt.calc.opt()` is given in [Kakushadze, 2015e]. One of its inputs is the inverse model covariance matrix for the stocks. This matrix is computed internally via functions such as `qrm.cov.pc()` and `qrm.erank.pc()`, which are given in and utilize the statistical risk model construction of [Kakushadze and Yu, 2017a], or `qrm.gen.het()`, which is given in and utilizes the heterotic risk model construction of [Kakushadze and Yu, 2016a]. The latter requires a multilevel binary industry classification. The code below builds such a classification via the function `qrm.stat.ind.class.all()`, which is given in and utilizes the statistical industry classification construction of [Kakushadze and Yu, 2016b]. However, the code can be straightforwardly modified to utilize a fundamental industry classification, such as GICS (Global Industry Classification Standard), BICS (Bloomberg Industry Classification System), SIC (Standard Industrial Classification), etc. One issue with this is that practically it is difficult to do this 100% out-of-sample. However, "in-

sampleness" of a fundamental industry classification – which is relatively stable – typically does not pose a serious issue in such backtests as stocks rarely jump industries. Furthermore, note that the aforesaid "external" functions have various other parameters (which are set to their implicit default values in the code below), which can be modified (see the references above that provide the aforesaid functions).

Finally, the code internally computes the desired holdings and various performance characteristics such as the total P&L over the backtesting period, annualized return, annualized Sharpe ratio, and cents-per-share. These and other quantities computed internally can be returned (e.g., via environments or lists), dumped into files, printed on-screen, etc. The code is straightforward and can be tweaked depending on the user's specific needs/strategies. Its purpose is illustrative/pedagogical.

```
qrm.backtest <- function (days = 252 * 5, d.r = 21, d.addv = 21,
   n.addv = 2000, inv.lvl = 2e+07, bnds = .01, incl.cost = F)
{
   calc.ix <- function(i, d, d.r)
   {
      k1 <- d - i
      k1 <- trunc(k1 / d.r)
      ix <- d - k1 * d.r
      return(ix)
   }

   calc.mv.avg <- function(x, days, d.r)
   {
      y <- matrix(0, nrow(x), days)
      for(i in 1:days)
         y[, i] <- rowMeans(x[, i:(i + d.r - 1)])

      return(y)
   }

   calc.mv.sd <- function(x, days, d.r)
   {
      y <- matrix(0, nrow(x), days)
      for(i in 1:days)
         y[, i] <- apply(x[, i:(i + d.r - 1)], 1, sd)

      return(y)
   }

   read.x <- function(file)
   {
```

```
   x <- read.delim(file, as.is = T)
   x <- as.matrix(x)
   mode(x) <- "numeric"
   return(x)
}

calc.sharpe <- function (pnl, inv.lvl)
{
   print(sum(pnl, na.rm = T))
   print(mean(pnl, na.rm = T) * 252 / inv.lvl * 100)
   print(mean(pnl, na.rm = T) / sd(pnl, na.rm = T) * sqrt(252))
}

ret <- read.x("nrm.ret.txt")
open <- read.x("nrm.open.txt")
close <- read.x("nrm.close.txt")
vol <- read.x("nrm.vol.txt")
prc <- read.x("nrm.prc.txt")

addv <- calc.mv.avg(vol * close, days, d.addv)
ret.close <- log(prc[, -ncol(prc)]/prc[, -1])
tr <- calc.mv.sd(ret.close, days, d.r)

ret <- ret[, 1:days]
prc <- prc[, 1:days]
close <- close[, 1:days]
open <- open[, 1:days]
close1 <- cbind(close[, 1], close[, -ncol(close)])
open1 <- cbind(close[, 1], open[, -ncol(open)])

pnl <- matrix(0, nrow(ret), ncol(ret))
des.hold <- matrix(0, nrow(ret), ncol(ret))

for(i in 1:ncol(ret))
{
   ix <- calc.ix(i, ncol(ret), d.r)
   if(i == 1)
      prev.ix <- 0

   if(ix != prev.ix)
   {
      liq <- addv[, ix]
      x <- sort(liq)
```

```
   x <- x[length(x):1]
   take <- liq >= x[n.addv]

   r1 <- ret.close[take, (ix:(ix + d.r - 1))]

   ### ind.list <- qrm.stat.ind.class.all(r1,
   ###    c(100, 30, 10), iter.max = 100)

   ### rr <- qrm.gen.het(r1, ind.list)

   rr <- qrm.cov.pc(r1)
   ### rr <- qrm.erank.pc(r1)

   cov.mat <- rr$inv.cov
   prev.ix <- ix
}

w.int <- rep(1, sum(take))
ret.opt <- ret ### DELAY-0 MEAN-REVERSION
### ret.opt <- -log(close/open) ### DELAY-1 MOMENTUM

if(incl.cost)
{
   lin.cost <- tr[take, i] / addv[take, i]
   lin.cost <- 1e-3 * lin.cost / mean(lin.cost)
}
else
   lin.cost <- 0

ret.lin.cost <- ret.opt[take, i]
ret.lin.cost <- sign(ret.lin.cost) *
   pmax(abs(ret.lin.cost) - lin.cost, 0)

des.hold[take, i] <- as.vector(bopt.calc.opt(ret.lin.cost, w.int,
   cov.mat, bnds * liq[take]/inv.lvl, -bnds * liq[take]/inv.lvl))

des.hold[take, i] <- -des.hold[take, i] *
   inv.lvl / sum(abs(des.hold[take, i]))

pnl[take, i] <- des.hold[take, i] *
   (close1[take, i]/open1[take, i] - 1)

pnl[take, i] <- pnl[take, i] - abs(des.hold[take, i]) * lin.cost
```

```
    }

    des.hold <- des.hold[, -1]
    pnl <- pnl[, -1]
    pnl <- colSums(pnl)
    calc.sharpe(pnl, inv.lvl)

    trd.vol <- 2 * sum(abs(des.hold/open1[, -1]))
    cps <- 100 * sum(pnl) / trd.vol
    print(cps)
}
```

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Glossary

absolute momentum: time-series momentum.

acquirer company: the company purchasing another company (target company) in a corporate acquisition.

activation function: a function that defines the output of a node (artificial neuron) in an artificial neural network given an input (or a set of inputs).

active investing (a.k.a. active management): an investment strategy that involves active (frequent) buying and selling of securities in a portfolio (cf. *passive investing*) with the view of exploiting (perceived) profit-generating opportunities.

actively managed ETF: an exchange-traded fund whose underlying portfolio allocation is actively managed.

adjusted price: a stock's price adjusted for splits and dividends.

adverse selection: an effect caused by smart order flow, whereby most limit orders to buy at the bid (sell at the ask) get filled when the market is trading through them downward (upward).

aggressive order: a market order, or a marketable limit order (to buy at the ask or higher, or to sell at the bid or lower).

aggressive order flow: order flow comprised of aggressive orders.

alpha: following common trader lingo, any reasonable "expected return" that one may wish to trade on.

alpha portfolio (a.k.a. alpha combo): a portfolio of (typically, a large number of) alphas combined with some weights.

alpha rotation: a type of ETF trading strategy.

American option: an option (e.g., call or put) that can be exercised on any trading day on or before expiration.

announcement days: days with important economic announcements such as FOMC announcements (cf. *non-announcement days*).

annualization factor: a multiplicative factor for annualizing a quantity.

annualized return: an average daily return times 252 (the number of trading days in a year).

annualized Sharpe ratio: a daily Sharpe ratio times the square root of 252 (the number of trading days in a year).

appraised value: an evaluation of a property's or some other valuable object's (e.g., jewelry) value at a given time.

arbitrage: taking advantage of a (perceived) mispricing (a.k.a. arbitrage opportunity) in one or more securities to make a profit.

arbitrage trade: a set of transactions executed with the view of exploiting an arbitrage opportunity.

artificial neural network (ANN): a computing system (inspired by the neural structure of a brain) of nodes (artificial neurons) linked by connections (akin to the synapses in a brain) that can transmit signals from one node to another.

Asian option: an option whose payoff is determined by the average underlying price over some preset time period.

ask (a.k.a. ask price, or offer, or offer price): the price at which a seller is willing (offering) to sell.

asset allocation: assigning weights (allocation percentages) to the assets in a portfolio, typically based on risk-reward considerations.

asset-backed security (ABS): a financial security collateralized by a pool of assets such as loans, mortgages, royalties, etc.

asset class: a group of securities with similar characteristics.

at-the-money (ATM) option: an option whose exercise price is the same as the current price of the underlying asset.

attachment (a.k.a. attachment point): the percentage of the underlying portfolio loss at which a tranche of a CDO (collateralized debt obligation) starts to lose value.

back leg: longer-maturity bonds in a yield curve spread strategy (flattener or steepener).

backspread: a type of options strategies.

backtest: a simulation of strategy performance using historical data.

backtesting period: the historical period over which a backtest is performed.

backwardation: when the futures curve (term structure) is downward-sloping.

bank deposit certificate (a.k.a. certificate of deposit, or CD): a savings certificate (a promissory note issued by a bank) with a fixed maturity date and interest rate.

banker's acceptance (BA): a short-term debt instrument issued by a company and guaranteed by a commercial bank.

bankruptcy: a legal status (imposed by a Court order) of a company that cannot repay debts to its creditors.

barbell: a bond portfolio consisting of bonds with only two (typically, short and long) maturities.

barrier option: an option that can be exercised only if the underlying security's price passes a certain level or "barrier".

base form (a.k.a. stem): in linguistics, the part of a word that is common to all its inflected variants.

basis point (bps): 1/100 of 1%.

basket: a portfolio of assets combined with some weights.

Bayes' theorem: $P(A|B) = P(B|A) \times P(A)/P(B)$, where $P(A|B)$ is the conditional probability of A occurring assuming B is true, and $P(A)$ and $P(B)$ are the probabilities of A and B occurring independently of each other.

bearish outlook: when a trader expects the market or a security to trade lower.

bearish strategy: a directional strategy where the trader profits if the underlying instrument's price goes down.

Bermudan option: an option that can be exercised only on specified dates on or before expiration.

Bernoulli probability distribution: a discrete probability distribution of a random variable which takes the value 1 with probability p and the value 0 with probability $q = 1 - p$.

bias: in an artificial neural network, the inhomogeneous component of the argument of an activation function.

bid (a.k.a. bid price): the price at which a buyer is willing to buy.

bid-ask spread: ask price minus bid price.

binary industry classification: an industry classification where each company belongs to one and only one sub-industry, industry, sector, etc.

binary option (a.k.a. digital option, or all-or-nothing option): an option that pays a preset amount, say, \$1, if the underlying security meets a predefined condition on expiration, otherwise it simply expires without paying anything to the holder.

bisection method: a root-finding method that repeatedly bisects an interval and selects a subinterval in which a root must lie for further examination.

Bitcoin (BTC): the world's first decentralized digital currency (cryptocurrency).

black-box algorithm: an algorithm that can be viewed in terms of its inputs and outputs, without any knowledge of its internal workings.

Black-Scholes model (a.k.a. Black-Scholes-Merton model): a mathematical model of stock (or other underlying asset) dynamics used in pricing options and other derivatives, where the log of the underlying price is described by a Brownian motion with a constant drift.

blockchain: a distributed ledger for keeping a record of all transactions that consists of a sequential chain of blocks, linked using cryptography and time-stamping, and containing transaction records.

body: the middle (by maturity in bond portfolios, and by strike price in option portfolios) leg of a butterfly portfolio.

bond: a fixed-income instrument, a promise of being paid some amount (principal) at some future time T (maturity), and possibly some smaller amounts (coupon

payments) at some times prior to T.

bond immunization: matching the duration of a bond portfolio to the maturity of a future cash obligation.

bond maturity: the time at which the principal of a bond is paid.

bond principal: the amount the borrower (bond issuer) owes to the bondholder in full at bond maturity.

bond value: the worth of a bond at a given time before maturity.

bond yield (here, yield to maturity): the overall interest rate earned assuming the bond is held until maturity and all coupon and principal payments are made as promised.

bond yield spread (a.k.a. bond spread): the spread between the bond yield and the risk-free rate.

bondholder: bond owner.

book-to-market ratio: the company's total book value divided by its market capitalization (same as B/P ratio).

book-to-price ratio (a.k.a. B/P ratio): the company's book value per share outstanding divided by its stock share price.

book value: the company's total assets minus its total liabilities.

Boolean: a binary variable with only two possible values, `TRUE` and `FALSE`.

box: an option trading strategy.

break-even price (a.k.a. break-even point): a price of the underlying security (e.g., stock) in an option trading strategy at which it breaks even (i.e., when the P&L is zero).

breakeven rate: the fixed rate of an inflation swap.

broad market index: an index based on a broad cross-section of securities (e.g., S&P 500, Russell 3000, etc.).

brownfield project: a project associated with established infrastructure as-

sets in need of improvement.

Brownian motion (a.k.a. Wiener process): a continuous-time (t) stochastic process W_t, where $W_0 = 0$, W_t is a normal random variable with mean 0 and variance t, and the increment $W_{s+t} - W_s$ is a normal random variable with mean 0 and variance t and is independent of the history of what the process did up to time s.

Btu: British thermal unit, approximately 1,055 Joules.

bubble (a.k.a. economic, asset, speculative, market, price or financial bubble): an asset trading at prices strongly inflated compared with its intrinsic value.

bullet: a bond portfolio where all bonds have the same maturity.

bullish outlook: when a trader expects the market or a security to trade higher.

bullish strategy: a directional strategy where the trader profits if the underlying instrument's price goes up.

butterfly: a portfolio (of bonds or options) with 3 legs, two peripheral (by maturity in bond portfolios, and by strike price in option portfolios) wings and a body in the middle.

butterfly spread: a butterfly option strategy.

buy-and-hold asset/investment: an asset/investment for a passive long-term strategy where the investor holds a long position irrespective of short-term fluctuations in the market.

buy-write strategy: buying stock and writing (selling) a call option against the stock position.

calendar spread (for futures): buying (selling) a near-month futures and selling (buying) a deferred-month futures.

calendar spread (for options): buying a longer-expiration option (call or put) and selling a shorter-expiration option (of the same type, for the same underlying, and with the same strike price).

call option (a.k.a. call): see *European call option, option.*

Canary option: an option that can be exercised, say, quarterly, but not before

a determined time period, say, 1 year, has elapsed.

cancel-replaced order: a placed order that has been subsequently canceled and replaced with another order.

canceled order: a placed order that has been subsequently canceled.

capital allocation: see *asset allocation*.

capital gain strategy: a strategy that profits from buying and selling an asset (or, more generally, establishing and liquidating a position).

Carhart's momentum factor (a.k.a. MOM): winners minus losers by (12-month) momentum.

carry (a.k.a. cost of carry): a return (positive or negative) from holding an asset.

carry trade (a.k.a. carry strategy): a strategy based on earning a spread between borrowing a low carry asset and lending a high carry asset.

cash (for indexes): in common trader lingo, "cash" refers to the underlying index portfolio (e.g., the S&P 500 stocks for the S&P 500 index).

cash-equivalent asset: a highly liquid short-term investment security with high credit quality (e.g., REPO).

cash flow: the net amount of cash and cash-equivalent assets being transferred into and out of a company (in the business context) or a portfolio (in the trading context).

cash flow shortfall: the amount by which a financial obligation or liability exceeds the amount of cash (or, more generally, liquid funds) that is available.

cash merger: a merger where the acquirer company pays the target company's shareholders cash for its stock.

CDO tranche: a part of a CDO consisting of assets with different credit ratings and interest rates.

CDO tranche spread: for achieving a null MTM of a CDO tranche, the value of the default leg of the tranche divided by its risky duration.

CDS basis: CDS spread minus bond yield spread.

CDS basis arbitrage (a.k.a. CDS arbitrage): buying a bond and insuring it with a CDS.

CDS index: a credit default swap index such as CDX and iTraxx.

CDS spread: a periodic (e.g., annual) premium per dollar of the insured debt.

cents-per-share (CPS): the realized P&L in cents (as opposed to dollars) divided by the total shares traded (which includes both establishing and liquidating trades).

channel: a range/band, bounded by a ceiling and a floor, within which the stock price fluctuates.

Chapter 11: a chapter of Title 11, the United States Bankruptcy Code.

cheap stock: a stock that is perceived to be undervalued by some criterion.

claim: the payoff of an option (or some other derivative).

class: in machine learning, one of the possible predicted outcomes of a machine learning algorithm.

close (a.k.a. close price, or closing price): the closing price of a stock at the NYSE close (4:00 PM Eastern Time).

close-to-close return: the return from the close of the previous trading day to the close of the current trading day.

close-to-open return: the return from the close of the previous trading day to the open of the current trading day.

clustering algorithm: grouping objects (into clusters) based on some similarity criterion (or criteria).

Cochrane-Piazzesi predictor: a bond return predictor.

collar (a.k.a. fence): an option trading strategy.

collateral: something of value pledged as security for repayment of a loan, forfeited if the borrower defaults.

collateralized debt obligation (CDO): an asset-backed security (ABS) consisting of a basket of assets such as bonds, credit default swaps, etc.

combo (for options): a type of option trading strategies.

commercial paper: short-term unsecured promissory notes issued by companies.

commercial real estate: real estate property used for business purposes (rather than living space), e.g., shopping centers, retail shops, office space, etc.

Commitments of Traders (COT): weekly reports provided by CFTC.

commodity: a raw material (e.g., gold, silver, oil, copper) or an agricultural product (e.g., wheat, soy, rice) that can be bought and sold.

commodity allocation percentage (CA): the allocation weight for commodities included as an inflation hedge in a portfolio of other assets.

commodity futures: futures contracts on commodities.

common stock: a security representing ownership in a corporation entitling its holder to exercise control over the company affairs (e.g., via voting on electing a board of directors and corporate policy), with the lowest priority (after bondholders, preferred stockholders, etc.) for rights to the company's assets in the event of its liquidation.

compounding: reinvestment of interest earned to generate additional interest in the future.

compounding period: the period between two consecutive points in time when interest is paid or added to the principal.

conditional expectation (a.k.a. conditional expected value, or conditional mean): an average value of a quantity assuming some condition occurs.

conditional independence: A and B are conditionally independent assuming C is true iff the occurrence of A assuming C is independent from the occurrence of B assuming C and vice versa, i.e., $P(A \cap B|C) = P(A|C) \times P(B|C)$, where $P(A|B)$ is a conditional probability.

conditional probability: $P(A|B)$, the probability of A occurring assuming

B is true.

condor: a type of options strategies.

constrained regression: a linear regression subject to a set of linear or non-linear constraints, e.g., non-negative least squares (NNLS), where the regression coefficients are required to be nonnegative.

Consumer Price Index (CPI): a measure of the price level of a market basket of consumer goods and services.

contango: when the futures curve (term structure) is upward-sloping.

contingent leg: in a CDO, the default leg, the other leg being the premium leg.

continuous compounding: an idealized mathematical limit of compounding where the number of compounding periods n goes to infinity, the length δ of each compounding period goes to zero, and the product $n \times \delta$ is kept fixed and finite.

contrarian effect: see *mean-reversion effect*.

control rights: the legal entitlements granted to an investor (e.g., a shareholder holding common stock), such as the right to transfer shares, receive regular and accurate financial disclosure, vote on specific issues at the company, etc.

conversion factor: the quoted price a bond would have per dollar of principal on the first day of the delivery month of an interest rate futures contract assuming that the interest rate for all maturities equals 6% per annum with semiannual compounding.

conversion factor model: a model (based on the conversion factor) commonly used to calculate hedge ratios when hedging interest rate risk with interest rate futures.

conversion price: the price of the underlying stock at which a convertible bond can be converted into stock.

conversion ratio: the number of the issuer's stock shares into which a convertible bond can be converted.

convertible arbitrage: a trading strategy involving a convertible bond and stock of the same issuer.

convertible bond: a hybrid security with an embedded option to convert a bond to a preset number (conversion ratio) of the issuer's stock when, e.g., the stock price reaches a preset level (conversion price).

convexity (for bonds): a measure of non-linear dependence of bond prices on changes in interest rates, which involves the second derivative of the bond price w.r.t. the interest rates.

core inflation (CI): long run inflation, with items subject to volatile prices (such as food and energy) excluded (cf. *headline inflation*)

corporate actions: events initiated by a publicly traded company such as stock splits, dividends, mergers and acquisitions (M&A), rights issues, spin-offs, etc.

correlation: a measure of how closely two securities move in relation to each other, defined as the covariance of their returns divided by a product of the standard deviations of said returns.

correlation matrix: an $N \times N$ matrix with unit diagonal elements, whose off-diagonal elements are the pair-wise correlations of N different securities.

correlation trading: arbitraging the average pair-wise correlation of the index constituents vs. its future realized value.

counterparty: the other party that participates in a financial transaction.

coupon bond: a bond that makes periodic coupon payments before maturity.

coupon rate: an uncompounded, fixed or variable rate at which a coupon bond makes coupon payments.

covariance: a mean value of the product of the deviations of the returns of two securities from their respective mean values.

covariance matrix: an $N \times N$ matrix, whose off-diagonal elements are the pair-wise covariances of N different securities, and whose diagonal elements are the corresponding variances.

covered call: see *buy-write strategy.*

covered interest arbitrage: a trading strategy that exploits deviations from CIRP.

covered put: see *sell-write strategy.*

credit default swap (CDS): a swap that provides insurance against default on a bond.

credit derivatives: financial contracts (e.g., CDS) that allow parties to transfer or receive exposure to credit risk.

credit rating (for bonds): a measure of the creditworthiness of corporate or government bonds (e.g., S&P's credit ratings AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, BBB-, BB+, BB, BB-, B+, B, B-, CCC+, CCC, CCC-, CC, C, D).

credit spread: the difference between the bond yield and the risk-free rate (same as the bond yield spread).

cross-border tax arbitrage: exploiting differences in the tax regimes of two or more countries.

cross-hedging: managing risk exposure to one security by taking an opposite position (with some hedge ratio) in another security (or its derivative, e.g., futures), where the two securities are positively correlated and have similar price movements.

cross-sectional quantity: a quantity (e.g., mean, standard deviation, etc.) computed across a set of securities (e.g., stocks in a portfolio) as opposed to serially (i.e., across a time series for each security).

cross-sectional regression: a regression where the independent variables are vectors whose elements are labeled by a cross-sectional index, e.g., that which labels stocks in a portfolio (cf. *serial regression*).

cross-validation (a.k.a. out-of-sample testing): a technique to evaluate predictive models by partitioning the original data sample into a training set to train the model, and a test set to evaluate it.

cryptoassets: cryptocurrencies and similar digital assets.

cryptocurrency: a digital medium of exchange that uses cryptography (e.g., BTC).

cryptography: constructing and analyzing protocols that prevent third parties from reading private messages.

cum-dividend: when the stock buyer is entitled to receive a dividend that has been declared but not paid (cf. *ex-dividend*).

cumulative inflation: inflation rate measured from time t_1 to time t_2 (cf. *year-on-year inflation*).

cumulative return: an asset's return from time t_1 to time t_2.

curvature: in a yield curve, the change in the slope thereof as a function of maturity.

curve-neutrality: approximate neutrality of a bond portfolio to small steepening and flattening of the yield curve.

curve trade: a flattener or steepener (in bonds or CDOs).

daily roll value: futures basis divided by the number of business days until the settlement.

dark spread: the difference between the wholesale price of electricity and the price of coal required to produce it by a coal-fired power plant.

data mining: a process of finding patterns/trends in large data sets.

debt seniority: the order of repayment of debt in the event of a sale or bankruptcy of the debt issuer.

decentralized digital currency: a decentralized cryptocurrency such as BTC, ETH, etc.

decile: each of the 10 (approximately) equal parts of a sample (e.g., data sample).

default: a failure to repay a loan/debt.

default risk: the (estimated/perceived) risk of a default of a borrower.

deferred-month futures: a futures contract with the settlement date in the later months (cf. *front-month futures*).

delay-d backtest: a backtest in which all quantities used for establishing or liquidating simulated positions at any given time t are computed using historical quantities from times at least d trading days prior to t.

deliverable bond: a bond in the delivery basket of an interest rate futures contract.

delivery: transferring the underlying instrument (or commodity) in a contract (e.g., futures or forward) to the buyer at maturity (delivery date) at a pre-agreed price (delivery price).

delivery basket: in interest rate futures, the array of bonds that can be delivered at the delivery date.

delivery month: the month in which the delivery in a futures contract occurs.

Delta: the first derivative of the value of a derivative asset (e.g., option) w.r.t. the price of the underlying asset.

Delta-hedge: hedging a long (short) position in a derivative asset with a short (long) position in the underlying asset with the hedge ratio equal the Delta of the derivative asset.

Delta-neutral strategy: a trading strategy which achieves null Delta via, e.g., Delta-hedging.

demeaning: subtracting from the elements of a sample their mean value across said sample.

derivative (a.k.a. derivative contract, or contingent claim): a security (e.g., option) whose future payoff depends on the value of its underlying asset (e.g., stock) and is contingent on some uncertain future event.

desired holdings: portfolio holdings to be attained by a trading strategy.

detachment (a.k.a. detachment point): the percentage of the underlying portfolio loss at which a tranche of a CDO (collateralized debt obligation) loses all its value.

diagonal spread: an option trading strategy.

dimnames: a command in R for the names of column and row labels of a matrix.

directional strategy: a strategy that profits based on the underlying secu-

rity's (or securities') future direction (cf. *non-directional strategy*).

discount bond (a.k.a. zero-coupon bond): a bond that pays only its principal at maturity but makes no coupon payments.

discount factor: the worth of a discount bond with \$1 principal at time t prior to its maturity T.

discount rate (a.k.a. Fed discount rate, or Federal discount rate): the interest rate charged to commercial banks and other depository institutions for loans received from the U.S. Federal Reserve.

discretionary strategy: a strategy that relies on the fund manager's skills (cf. *systematic strategy*).

discretionary macro: discretionary global macro strategies based on analysts' subjective opinions.

dispersion trading: arbitraging the index implied volatility vs. implied volatilities of its constituents.

distress risk puzzle: an empirical occurrence that companies with lower bankruptcy risk tend to yield higher returns than riskier ones.

distressed asset: an asset (e.g., debt) of a distressed company.

distressed debt: see *distressed asset*.

distressed debt strategy: strategies based on acquiring debt of a distressed company.

distressed company: a company undergoing financial or operational distress.

distributed ledger: a database shared and synchronized across a (typically large, peer-to-peer) network encompassing multiple sites.

diversification: allocating capital to reduce exposure to any one particular asset or risk by investing in a variety of assets.

dividend: a distribution of some of the earnings of a company, as decided by its board of directors, to a class of its shareholders, usually (but not always) quarterly.

dividend imputation: a corporate tax system in which some or all of the

tax paid by a company may be attributed, or imputed, to the shareholders via a tax credit to reduce the income tax payable on a distribution via, e.g., dividends.

dollar carry trade: an FX trading strategy.

dollar duration: a measure of the absolute bond price sensitivity to changes in the interest rates, defined as the modified duration times the bond price.

dollar-duration-neutrality: when the sum of dollar durations of a bond portfolio is null (with dollar durations of short bond positions defined to be negative).

dollar holding (a.k.a. dollar position): the dollar value of an asset's position in a portfolio.

dollar-neutrality: when the sum of dollar holdings in a portfolio is null (with dollar holdings of short positions defined to be negative).

domestic currency: the currency of the investor's home country.

Donchian Channel: a commonly used definition of a channel in channel trading strategies.

double-taxation: a corporate taxation system (e.g., in the U.S.) where the corporate income is first taxed at the corporate level, and then again when dividends are received by the shareholders.

downside risk: the risk associated with losses.

drawdown: a peak-to-trough decline in the P&L during a given period, where the peak (trough) is defined as the P&L maximum (minimum) in said period.

drift: a mean change in a time-dependent quantity over a period of time, i.e., a serial mean.

dual-momentum sector rotation: an ETF momentum strategy.

dumb order flow (a.k.a. uninformed order flow): aggressive order flow not based on a predictive expected return.

dummy variable (a.k.a. binary variable): a predictor variable taking binary values 0 or 1 to indicate the absence or presence of some effect or belonging or not belonging to some category that may affect the outcome (e.g., if a company belongs to a given economic sector).

duration: see *dollar duration, Macaulay duration, modified duration, risky duration.*

duration-hedging: hedging duration risk (i.e., interest rate risk) with interest rate swaps or interest rate futures.

duration-targeting strategy: a strategy (e.g., a bond ladder) that maintains an approximately constant duration by selling shorter-maturity bonds as they approach maturity and replacing them with new longer-maturity bonds.

dynamic asset allocation: frequently adjusting the asset allocations in a portfolio according to changing market conditions.

earnings: the after-tax net income of a company.

earnings-momentum: a momentum strategy based on earnings.

economic activity: production, distribution, exchange and consumption of goods and services.

economic data: data (typically, time series) pertaining to an actual economy.

eigenvalue: a root of the characteristic equation of a matrix (see *eigenvector*).

eigenvector: for a square symmetric $N \times N$ matrix A, an N-vector V that solves the characteristic equation $A\,V = \lambda\,V$, where λ is the corresponding eigenvalue (which is a number).

electronic trading: trading securities electronically, as opposed to by human traders on the trading floors of the exchanges.

EMA: an exponential moving average, a serial moving average with past contributions suppressed with exponentially decreasing weights.

embedded option: in a convertible bond, the option to convert the bond to a preset number of the issuer's stock.

EMSD: an exponential moving standard deviation, a serial moving standard deviation with past contributions suppressed with exponentially decreasing weights.

equally-weighted portfolio: a portfolio where all assets have equal dollar

holdings.

equity: a company's stock or other security representing its ownership interest.

equity market: a stock market.

equity tranche: the lowest quality tranche of a CDO.

eRank (a.k.a. effective rank): a measure of effective dimensionality of a matrix.

error function: in machine learning, a function to be minimized that is constructed from the errors (or similar), e.g., the sum of squares of the errors, or some other suitable function (not to be confused with the Gauss error function $\mathrm{erf}(x)$).

establishing: buying or shorting an asset or portfolio from a null position.

estimation period: the length of a time-series data sample used in estimating some parameters, e.g., regression coefficients.

ETH: ether/Ethereum, a cryptocurrency.

Euclidean distance: the distance between two vectors defined as the square root of the sum of squares of the differences between their components.

EUR: euro, a unit of the eurozone currency.

eurodollar: a USD deposit held in a bank outside the U.S.

European call option: a right (but not an obligation) to buy a stock at the maturity time T for the strike price k agreed on at time $t = 0$.

European put option: a right (but not an obligation) to sell a stock at the maturity time T for the strike price k agreed on at time $t = 0$.

ex-dividend when the stock seller is entitled to receive a dividend that has been declared but not paid (cf. *cum-dividend*).

excess return: a return of an asset in excess of some benchmark return (e.g., risk-free rate).

exchange rate (a.k.a. FX rate): the rate of exchange between two dif-

ferent currencies.

execution price: the price at which an order (e.g., to buy stock) is filled (executed).

exercise date: a date on which an option can be exercised.

exotic options: a broad category of options that typically are complexly structured.

expected return: a future return of an asset expected based on some reasonable consideration, e.g., an average realized return over some past period.

expiration: the last date on which a derivatives contract (e.g., option or futures) is valid.

explanatory variable: a variable that has (or is expected to have) some explanatory power for an observed variable (e.g., hours studied by a student for a final exam can be expected to be an explanatory variable for the student's final exam grade/score).

exponential smoothing parameter: the exponential suppression factor in an exponential moving average.

exposure: the amount that can be lost (or gained) in an investment.

face value (a.k.a. principal): the amount paid to the bondholder at maturity.

factor (a.k.a. risk factor): a common explanatory variable for a cross-section of asset returns (e.g., stocks).

factor loadings matrix: the $N \times K$ matrix Ω_{iA} ($i = 1, \ldots, N$, $A = 1, \ldots, K$, typically $K \ll N$) in a K-factor model $Y_i = \sum_{A=1}^{K} \Omega_{iA}\ F_A + \epsilon_i$, where Y_i are the observed variables, F_A are the unobserved variables (common factors), and ϵ_i are the unobserved error terms.

factor portfolio: a portfolio that aims to attain exposure to a given factor.

fair value: a market value of a security or, in the absence of a market value, a theoretical value based on some reasonable modeling.

Fama-French factors: MKT, the excess return (defined as the return in excess of the risk-free rate, in turn defined as the one-month Treasury bill rate) of

the market portfolio; SMB, the excess return of the Small minus Big (by market capitalization) portfolio; HML, the excess return of the High minus Low (by book-to-market) portfolio.

Fama puzzle: see *forward discount anomaly.*

feature (in machine learning): a predictor, an input variable.

fiat currency: a legal tender declared by a government (e.g., U.S. dollar) but not backed by a physical commodity (such as gold).

fill: when an order to buy or sell a security or commodity is completed, with a partial completion (e.g., only 100 shares of a 200 share buy order are filled) known as a partial fill.

fill or kill limit order (a.k.a. FOK): a limit order to buy or sell stock that must be executed immediately and completely or not at all (no partial fills are allowed).

financial crisis: when some financial assets suddenly lose a large part of their nominal value.

first-month contract: see *front-month futures.*

fix-and-flip: a real estate strategy.

fixed coupon bond (a.k.a. fixed rate coupon bond): a bond with a fixed (as opposed to variable) coupon rate.

fixed-income asset: a debt instrument that generates fixed returns in the form of interest payments.

fixed interest rate (a.k.a. fixed rate): an interest rate on a liability that remains unchanged either for the entire term of the loan or for its part.

fixed rate payment: a coupon payment of a fixed coupon bond.

flattener: a yield curve spread bond strategy.

floating coupon bond (a.k.a. floating rate coupon bond, or variable coupon bond, or variable rate coupon bond): a bond with a variable (as opposed to fixed) coupon rate.

floating interest rate (a.k.a. floating rate, or variable interest rate, or variable rate): interest rate on a liability that varies during the term of the loan.

floating rate payment: a coupon payment of a floating coupon bond.

FOMC announcements: Federal Open Market Committee announcements such as interest rate hikes.

forecasting future returns: predicting future returns.

foreign currency: a currency (that is different from the domestic currency) of a country other than the investor's home country.

formation period: in momentum strategies, the period over which the momentum indicator is computed.

forward (a.k.a. forward contract): a contract struck at time $t = 0$, where one of the two parties agrees to sell the other an asset at some future time T (known as the expiry, delivery date or maturity of the contract) for the pre-agreed strike price k.

forward discount: when the forward FX rate is lower than the spot FX rate.

forward discount anomaly (a.k.a. forward premium anomaly, or forward discount puzzle, or forward premium puzzle, or Fama puzzle): an empirical occurrence whereby on average high interest rate currencies tend to appreciate (somewhat) w.r.t. low interest rate currencies.

forward FX rate: the FX rate of a forward FX contract.

forward premium: when the forward FX rate is higher than the spot FX rate.

front leg: shorter-maturity bonds in a yield curve spread strategy (flattener or steepener).

front-month futures: a futures contract with the settlement date closest to the current date (cf. *deferred-month futures*).

fundamental analysis: evaluating securities based on fundamental data.

fundamental data: data pertaining to the fundamentals of stocks or other

securities, including time series and/or cross-sectional data.

fundamental industry classification: an industry classification of companies (into sectors, industries, sub-industries, etc.) based on fundamental/economic data, such as companies' products and services, revenue sources, suppliers, competitors, partners, etc. (cf. *statistical industry classification*).

fundamental trading strategy: a trading strategy based on fundamental analysis.

fundamentals: quantitative and qualitative information on the financial/economic health and valuation of a company, security, currency, etc.

futures (a.k.a. futures contract): a standardized forward contract traded on a futures exchange.

futures basis: the futures price minus the underlying spot price.

futures curve (a.k.a. futures term structure): the dependence of the futures prices on time to delivery.

futures delivery basket: see *delivery basket*.

futures spread: see *calendar spread (for futures)*.

FX pair: currencies of 2 different countries.

FX rate: see *exchange rate*.

FX rate risk: exposure to FX rate changes.

FX spot rate: see *spot FX rate*.

FX triangular arbitrage: arbitraging 3 FX pairs.

Gamma: the second derivative of the value of a derivative asset (e.g., option) w.r.t. the price of the underlying asset.

Gamma hedging: an options hedging strategy to eliminate or reduce the exposure caused by changes in an option portfolio's Delta as a result of the underlying security's price movements.

Gamma scalping: Gamma hedging by buying and selling the underlying secu-

rity in response to its price movements that cause changes in an option portfolio's Delta.

global macro: trading strategies seeking to capitalize on regional, economic and political changes around the world.

Greeks: see *Delta, Gamma, Theta, Vega.*

greenfield project: a project associated with infrastructure assets to be constructed.

guaranteed loan: a loan guaranteed by a third party in case the borrower defaults.

guts: an option trading strategy.

hard-to-borrow security: a security on a "Hard-to-Borrow List", an inventory record used by brokerages for securities that are difficult to borrow for short sale transactions due to short supply or high volatility.

headline inflation (HI): a measure of the total inflation within an economy, including commodity prices such as food and energy (cf. *core inflation*).

heat rate: the efficiency with which an electricity production plant converts fuel into electricity.

hedge: an investment (typically, via an offsetting position in a related security) to reduce the risk of losing money on an existing position.

hedge ratio: in a hedge, the number of units (or the dollar notional) of the offsetting security for each unit (or dollar) of the security to be hedged.

hedger: a market participant attempting to reduce risk associated with a security's price movement (cf. *speculator*).

hedging pressure (HP): in (commodities) futures markets, the number of long contracts divided by the total number of contracts (long plus short).

hedging strategy: see *hedge.*

heterotic risk model: a multifactor risk model combining a multilevel fundamental industry classification with principal component analysis.

hidden layers: in an artificial neural network, the intermediate layers of nodes (artificial neurons) between the input layer and the output layer.

high (a.k.a. high price): the maximum price attained by a stock (or other security) within a given trading day (or some other time interval).

high-minus-low carry: an FX trading strategy based on the forward discount anomaly.

High Yield bonds (a.k.a. junk bonds): bonds with S&P credit ratings below BBB-.

historical quantity: a quantity (e.g., correlation, variance, volatility, return, etc.) computed based on historical data.

HMD (a.k.a. healthy-minus-distressed): buying the safest companies and selling the riskiest ones by probability of bankruptcy.

HML (a.k.a. High minus Low): see *Fama-French factors*.

Hodrick-Prescott filter (a.k.a. HP filter, or Whittaker-Henderson method in actuarial sciences): a time-series filter for separating a lower-frequency ("regular") component from a higher-frequency ("irregular") component (noise).

holding period: the period for which a position in a security or a portfolio is held after being established and before being liquidated (or, more loosely, rebalanced).

holding weights: the weights with which assets are held in a portfolio.

holdings: the contents of a portfolio; also, a shorthand for, e.g., dollar holdings.

horizon (a.k.a. investment horizon): see *holding period*.

horizontal spread (a.k.a. time spread): see *calendar spread*.

Hybrid Market: a blend of an automated electronic trading platform and a traditional (human-operated) floor broker system.

hybrid security: a security with mixed characteristics of two asset classes, e.g., a convertible bond.

IBS: internal bar strength, defined as the difference between the close price

and the low price divided by the difference between the high price and the low price.

implied volatility: in option pricing, the volatility of the underlying instrument, which, when used as an input in an option pricing model (such as the Black-Scholes model), yields the model value of the option price equal to its market value.

imputation system: see *dividend imputation.*

in-sample: when a computation or backtest is not out-of-sample.

in-the-money (ITM) option: a call (put) option whose exercise price is below (above) the current price of the underlying asset.

income strategy: a trading strategy that generates income, usually via some risk exposure.

incomplete basket: a subset of the portfolio that would ideally be traded, e.g., in index arbitrage.

index: a diversified portfolio of assets combined with some weights.

index arbitrage (a.k.a. cash-and-carry arbitrage): an arbitrage strategy exploiting mispricings between the index spot price and index futures price (i.e., the index futures basis).

index basket: an index portfolio.

index constituents: the assets in an index portfolio.

index ETF: an ETF that tracks an index.

index futures: a futures on an index.

index hedging: hedging a position (e.g., a CDO tranche) with a pertinent index.

index level: for market cap weighted indexes, the current value of the index level $I(t) = I(0) \times C(t)/C(0)$, where $I(0)$ is the initial value of the index level (which is defined, not calculated), $C(t)$ is the current total market cap of the index constituents, and $C(0)$ is its initial value.

index spot price: the current market price of an index basket, where the number of units of each constituent is determined by the index weighting scheme

(market cap weighted index, price weighted index, etc.) with the overall normalization constant fixed depending on a specific purpose, e.g., to match the index portfolio to be delivered at the index futures delivery in the case of index arbitrage.

indexed payments: payments adjusted according to the value of some index, e.g., CPI in inflation swaps or TIPS.

industrial properties: commercial real estate properties including manufacturing buildings and property, warehouses, etc.

industry (in economy): a group of companies that are related based on their primary business activities.

industry (in industry classification): a grouping of companies based (among other things) on which economic industry they belong to.

industry classification: a taxonomy of companies (stocks) based on some similarity criterion (or criteria), e.g., a company's main source of revenues, how closely stock returns follow each other historically, etc.

inflation: a sustained increase in the price level of goods and services in an economy over a period of time, which is measured as an annual percentage change known as the inflation rate.

inflation hedge: a hedge against inflation.

inflation index: e.g., CPI.

inflation-indexed product: a security (e.g., TIPS) with indexed payments based on an inflation index.

inflation swap: a swap whose buyer is long the inflation and receives a floating rate (based on an inflation index) and pays a fixed rate (breakeven rate).

informed order flow: see *smart order flow*.

infrastructure funds: unlisted infrastructure funds (private equity-type investments), listed infrastructure funds (exchange-traded).

infrastructure investment: investing in long-term projects such as transportation (roads, bridges, tunnels, railways, ports, airports, etc.), telecommunications (transmission cables, satellites, towers, etc.), utilities (electricity generation, gas or electricity transmission or distribution, water supply, sewage, waste, etc.), en-

ergy (including but not limited to renewable energy), healthcare (hospitals, clinics, senior homes, etc.), educational facilities (schools, universities, research institutes, etc.), etc.

input layer: in an artificial neural network, the layer of nodes (artificial neurons) that processes the input data.

institutional trader: a trader who buys and sells securities for an account of a group or institution such as a pension fund, mutual fund, insurance company, ETF, etc.

integration: the final step of the money laundering process whereby money launderers get back the money via legitimate-looking sources.

intercept: in a linear regression, the regression coefficient of the independent variable (which is also colloquially referred to as the intercept) whose elements are all equal 1.

interest: the amount paid by the borrower to the lender above the principal (the actual amount borrowed).

interest rate: the interest per $1 of the principal.

interest rate futures: a futures contract typically with an array (delivery basket) of underlying instruments (e.g., bonds) that pay interest.

interest rate risk (a.k.a. interest rate exposure): the exposure to interest rate fluctuations, which affect bond and other fixed-income asset prices.

interest rate spread: the difference between the interest rates paid by two instruments.

interest rate swap: a contract that exchanges a stream of floating rate payments for a stream of fixed rate payments or vice versa.

intra-asset diversification: in real estate investments, diversification by property type (residential, commercial, etc.), economic diversification (by different regions divided according to economic characteristics), geographic diversification, etc.

intraday arbitrage: taking advantage of intraday mispricings, e.g., in ETFs and stocks.

intraday signal: a trading signal used by an intraday strategy.

intraday strategy: a trading strategy that starts with a null position, buys and sells/shorts securities intraday, and ends with a null position by the close (in trader lingo, "goes home flat").

inverse ETF: an ETF designed to track the return inverse to its underlying index.

inverse matrix: for an $N \times N$ square matrix A, the inverse matrix A^{-1} is the $N \times N$ square matrix such that $A\ A^{-1} = A^{-1}\ A = I$, where I is the $N \times N$ identity matrix (whose diagonal elements equal 1, and off-diagonal elements equal 0).

investment: allocating money with an expectation of a positive return.

Investment Grade bonds (a.k.a. IG bonds): bonds with S&P credit ratings AAA through AA- (high credit quality) and A+ through BBB- (medium credit quality).

investment vehicle: an investment product (e.g., ETF) used by investors for generating positive returns.

iron butterfly: a type of option trading strategies.

iron condor: a type of option trading strategies.

iShares (ticker IVV): an S&P 500 tracking EFT.

Jensen's alpha: an abnormal return of a security or portfolio, usually calculated as the intercept coefficient in a linear model, where excess returns of said security or portfolio are serially regressed over excess returns of one or more factor portfolios (e.g., MKT).

Joule: a unit of work, heat and energy in the International System of Units (SI).

JPY: Japanese Yen, a unit of Japanese currency.

junior mezzanine tranche: the next (by increasing quality) tranche of a CDO after the equity tranche.

k-nearest neighbor algorithm (a.k.a. KNN or k-NN): a statistical classification algorithm based on a similarity criterion such as distance, angle, etc., between multi-dimensional vectors.

Kalman filter: a time-series filter for separating signal from noise.

Kelly strategy: an allocation (betting) strategy based on maximizing the expectation of the logarithm of wealth.

keyword: in sentiment analysis (e.g., Twitter sentiment) using machine learning techniques, a word in the learning vocabulary pertinent to the goal (e.g., predicting stock or cryptocurrency price movements).

ladder (for bonds): a bond portfolio with (roughly) equal capital allocations into bonds of a sizable number of different (and usually approximately equidistant) maturities.

ladder (for options): a vertical spread consisting of 3 options, all 3 are call options or put options, 2 are long and 1 is short, or 1 is long and 2 are short.

Lagrange multiplier: when minimizing a (multivariate) function $g(x)$ w.r.t. x subject to a constraint $h(x) = 0$, an additional variable λ in the function $\widetilde{g}(x, \lambda) = g(x) + \lambda\, h(x)$, whose (unconstrained) minimization w.r.t. x and λ is equivalent to the original constrained minimization problem.

layer: see *input layer, output layer, hidden layer.*

layering: the middle step in the money laundering process, which amounts to moving the money around between different accounts and even countries thereby creating complexity and separating the money from its source by several degrees.

learning vocabulary: in sentiment analysis (e.g., Twitter sentiment) using machine learning techniques, a set of keywords pertinent to the goal (e.g., predicting stock or cryptocurrency price movements).

least squares: in regression analysis, minimizing the sum of squares of the residuals (possibly, with nonuniform weights).

ledger: a book or other collection of financial accounts and transaction records.

leg: a component in a trading portfolio, usually when a portfolio can be thought of as consisting of a relatively small number of groupings (e.g., short leg and long leg, referring to short and long positions, respectively).

LETF: leveraged (inverse) ETF, an ETF designed to track the return (inverse to) n times the return of its underlying index, where n is the leverage (usually, 2 or 3).

leverage: using borrowed funds to purchase an asset.

limit order: an order to buy or sell a stock (or other security) at a specified price or better.

linear homogeneous constraint: for an N-vector x_i $(i = 1, \ldots, N)$, a constraint of the form $\sum_{i=1}^{N} a_i\, x_i = 0$, where at least some a_i are nonzero.

linear regression (a.k.a. linear model): fitting data for the observable variable using a linear combination of some number of (linear or nonlinear) functions of independent variables, with or without the intercept.

liquid asset: an asset that can be converted into cash quickly with minimal transaction costs.

liquid U.S. stocks: a subset of U.S. listed stocks usually defined using ADDV and market cap filters (e.g., top 2,000 most liquid stocks by ADDV).

liquidation (for assets or portfolios): closing of the open positions.

liquidation (for companies): winding up (bringing to an end) a company's business and distributing its assets to claimants, usually when the company is insolvent.

liquidity: availability of liquid assets/funds.

loadings matrix: see *factor loadings matrix*.

loan: lending of money or another asset by one party (lender) to another (borrower).

loan shark: a lender offering a loan at excessively high interest rates.

loan-to-own strategy: financing a distressed company via secured loans with the view of obtaining equity with control rights if the company files for bankruptcy.

log: a logarithm (usually, unless specified otherwise, the natural logarithm).

log-return: the natural log of the ratio of an asset's price at time t_2 to its price at time t_1 $(t_2 > t_1)$.

log-volatility: a standard deviation of the natural logarithms of prices.

logistic regression (a.k.a. logit model): a statistical model typically applied to a binary dependent variable.

long-only: a portfolio or strategy with only long holdings.

long-run mean: in a mean-reverting Ornstein-Uhlenbeck process, the mean value of the state variable in the infinite time limit.

long-short: a portfolio or strategy with both long and short holdings.

lookback (a.k.a. lookback period): the length of a time-series data sample used in a backtest or historical computation.

losers: stocks or other assets in a portfolio or trading universe that underperform based on some criterion (benchmark).

low (a.k.a. low price): the minimum price attained by a stock (or other security) within a given trading day (or some other time interval).

low-volatility anomaly: an empirical occurrence that future returns of previously low-return-volatility portfolios outperform those of previously high-return-volatility portfolios.

Macaulay duration: a weighted average maturity of a bond's cash flows, where the weights are the present values of said cash flows.

machine learning (ML): a method of data analysis that automates predictive analytical model building based on the premise that computational systems can "learn" from data, identify patterns and make decisions with minimal human intervention.

macro: macro trading strategies.

Manhattan distance: the distance between two vectors defined as the sum of the absolute values of the differences between their components.

margin account: a brokerage account in which the broker lends the customer cash to purchase securities.

mark-to-market (MTM): valuing assets or portfolios based on the most recent pertinent market prices.

market: a medium that allows buyers and sellers to interact to facilitate an exchange of securities, commodities, goods, services, etc.

market beta: a measure of the volatility (systematic risk) of an asset or portfolio in comparison to the broad market.

market capitalization (a.k.a. market cap, or cap): the market value of a company's shares outstanding.

market crash: a sudden dramatic decline of asset prices across their significant cross-section.

market data: price and trade-related data for a financial security reported by a trading exchange (or similar).

market-making: providing liquidity by simultaneously quoting both buy and sell prices in a financial instrument or commodity held in inventory with the view of making a profit on the bid-ask spread.

married call: see *protective call*.

married put: see *protective put*.

maturity (a.k.a. maturity date, or maturity time): the time at which a financial instrument will cease to exist and any principal and/or interest are repaid in full.

mean: an average value.

mean-reversion effect (a.k.a. mean-reversion, or contrarian effect): a tendency of asset prices and/or their returns to revert to their mean values, which mean values can be serial and/or cross-sectional, depending on the context.

mean-reversion parameter: in a mean-reverting Ornstein-Uhlenbeck process, the parameter that controls the rate of mean-reversion.

mean-reversion strategy: a trading strategy based on a mean-reversion effect.

mean-variance optimization: an optimization technique for constructing a portfolio of assets such that its expected return is maximized for a given level of its risk.

Megawatt: 1,000,000 watts.

Megawatt hour (Mwh): 1,000,000 watts times 1 hour, which equals 3.6×10^9 Joules.

merger: a consolidation of two companies into one.

merger arbitrage (a.k.a. risk arbitrage): a trading strategy that attempts to capture excess returns generated via corporate actions such as mergers and acquisitions (M&A).

metropolitan statistical area (MSA): a core area containing a substantial population nucleus, together with adjacent communities having a high degree of economic and social integration with that core.

mini-S&P futures (a.k.a. e-mini): a futures contract on S&P 500 with the notional value of 50 times the value of the S&P 500 stock index.

mishedge: an imperfect hedge, or when a hedge becomes undone (e.g., by underlying price movements).

mispricing: an inefficiency in the pricing of a security, when its price does not match its intrinsic value or (perceived) fair value.

MKT: see *Fama-French factors*.

modified duration: a measure of the relative bond price sensitivity to changes in the interest rates, defined as the negative first derivative of the bond price w.r.t. the bond yield.

MOM: see *Carhart's momentum factor*.

momentum (a.k.a. momentum effect): an empirical occurrence whereby assets' future returns are positively correlated with their past returns.

momentum strategy: a trading strategy based on momentum.

monetary policy: usually by a central bank, a process by which the monetary authority of a country controls the size and rate of growth of the money supply, via modifying the interest rates, buying or selling government bonds, and changing the required bank reserves (the amount of money banks are required to keep in their vaults).

money laundering: an activity wherein cash is used as a vehicle to trans-

form illegal profits into legitimate-appearing assets.

moneyness: where a derivative contract's strike price is in relation to its underlying asset's current price, which determines the derivative's intrinsic value.

mortgage: a debt instrument, secured by a real estate property as a collateral, that the borrower is obligated to pay back with a predetermined set of payments.

mortgage-backed security (MBS): an asset backed by a pool of mortgages.

moving average (a.k.a. rolling average): in a time series, an average (possibly computed with nontrivial weights) over a time interval of fixed length (moving average length), where the most recent time in said interval can take various values in the time series.

moving standard deviation: in a time series, a standard deviation (possibly computed with nontrivial weights) over a time interval of fixed length, where the most recent time in said interval can take various values in the time series.

multi-currency arbitrage: arbitraging 4 or more FX pairs.

multifactor risk model: a risk model based on a number (which can be sizable) of risk factors.

multifactor strategy: a trading strategy based on combining exposures to multiple factors, e.g., momentum, value, etc. (multifactor portfolio).

multinomial probability distribution: a discrete probability distribution of a random variable which takes k different values with probabilities $p_1, \ldots, p_k$.

municipal bond (a.k.a. muni bond): a bond issued by a local government/territory or its agency.

municipal bond tax arbitrage: a trading strategy based on borrowing money and buying tax-exempt municipal bonds.

mutual fund: an investment vehicle funded by a pool of money collected from many investors for the purpose of buying various securities (stocks, bonds, money market instruments, etc.).

naked call: a stand-alone short call option.

naked put: a stand-alone put call option.

near-month contract: see *near-month futures*.

near-month futures: see *front-month futures*.

neutral curve butterfly: a bond butterfly strategy with curve-neutrality.

neutral outlook: when a trader expects the market or a security to trade around its current level.

no-risk-free-arbitrage condition: a condition that ensures that no risk-free profits can be made by a trading strategy (at least, in excess to the risk-free rate).

node: in an artificial neural network, an artificial neuron, which (using an activation function) processes a set of inputs and generates an output.

noise: in a financial time series, random fluctuations without any apparent trend.

non-announcement days: days without any important economic announcements such as FOMC announcements (cf. *announcement days*).

non-deliverable bond: a bond not in the delivery basket of an interest rate futures contract.

non-directional strategy (a.k.a. neutral strategy): a strategy not based on the underlying security's (or securities') future direction, so the trader is oblivious to whether its price goes up or down (cf. *directional strategy*).

non-discretionary strategy: a trading strategy based on a systematic approach (as opposed to discretionary).

non-systematic risk: specific (a.k.a. idiosyncratic) risk, which is specific to each company, asset, etc., and exposure to which can be reduced via diversification, albeit never completely eliminated (cf. *systematic risk*).

nonlinear least squares: least squares used to fit a set of observations with a model that is nonlinear in the unknown parameters (regression coefficients).

notional (a.k.a. notional value): the total (dollar) value of a position.

objective function: a function to be maximized or minimized in optimization.

open (a.k.a. open price, or opening price): the opening price of a stock at the NYSE open (9:30 AM Eastern Time).

open interest (a.k.a. open contracts, or open commitments): the total number of open futures (or options) contracts at any given time (i.e., those contracts that have not been settled).

optimal hedge ratio: a hedge ratio calculated by minimizing the variance of a hedged portfolio.

optimization: see *portfolio optimization*.

option: a financial derivative contract that gives the buyer (option holder) the right (but not the obligation) to buy (call option) or sell (put option) the underlying asset at an agreed-upon price during a predefined period of time or on a specific date.

option-adjusted spread (OAS): a parallel shift in the Treasury curve (or some other benchmark yield curve) that matches a security's price calculated based on a pricing model to its market value, with the view to account for the security's embedded options.

option premium: the cost charged by the option seller to the option buyer.

option writer: an option seller.

order: an investor's instructions to a broker or brokerage firm to purchase or sell a security.

order execution system: a software component that executes trades based on input buy and/or sell order sequences.

Ornstein-Uhlenbeck process: Brownian motion with mean-reversion.

orthogonality: vectors x_i and y_i $(i = 1, \ldots, N)$ are orthogonal if $\sum_{i=1}^{N} x_i\, y_i = 0$.

out-of-sample backtest: a backtest in which all quantities used for establishing or liquidating simulated positions corresponding to any given time t are computed using historical quantities from times prior to t.

out-of-sample computation: a computation where all quantities to be used for forecasting purposes at any given simulated time t are computed using historical quantities from times prior to t.

out-of-the-money (OTM) option: a call (put) option whose exercise price is above (below) the current price of the underlying asset.

outcome (a.k.a. class): in machine learning, one of the possible results (outputs, predictions) of a machine learning algorithm.

output gap: the difference between the actual output of an economy and its maximum potential output as a percentage of GDP.

output layer: in an artificial neural network, the layer of nodes (artificial neurons) that generates the output data (the result).

over-fitting: in a statistical model, fitting more free parameters than justified by the data, thereby (often unwittingly) essentially fitting noise and rendering the model unpredictive out-of-sample.

overnight return: broadly, a return from some time during the previous trading day to some time during the current day (e.g., close-to-open return, close-to-close return); usually, close-to-open return.

overreaction: in financial markets, an irrational response by market participants (based on greed or fear) to new information.

pairs trading: a mean-reversion strategy involving two historically correlated assets.

parallel shift: in a yield curve, all interest rates for all maturities changing by the same amount.

passive investing: a longer-horizon, essentially buy-and-hold, investment strategy with the view of minimizing transaction costs and replicating the performance of a (typically, well-diversified) benchmark portfolio.

passive limit order: a liquidity-providing limit order to buy at the bid (or lower) or sell at the ask (or higher).

passive trading strategy: a trading strategy based on the passive investing approach.

passthrough MBS: an MBS where cash flows are passed from debtors to investors through an intermediary.

pawnbroker: a lender that extends a secured cash loan with pre-agreed interest and period (which can sometimes be extended), where the loan is secured with a collateral (forfeited if the borrower defaults), which is some valuable item(s), such as jewelry, electronics, vehicles, rare books or musical instruments, etc.

payment period: the period between two consecutive bond coupon payments.

payoff: the amount the option seller pays to the option buyer if and when the option is exercised.

peer-to-peer (P2P) network: a distributed computing application architecture with workload partitioned between equally privileged peers.

pension fund: a pool of funds that provides retirement income.

performance characteristics: for a portfolio or strategy, characteristics such as return-on-capital, Sharpe ratio, cents-per-share, maximum drawdown, etc.

periodic compounding: compounding with equal compounding periods, e.g., quarterly, semiannual or annual compounding.

physical commodity: the actual commodity (e.g., copper) that is delivered to a commodity futures contract buyer at the expiration.

pivot point (a.k.a. center): in support and resistance strategies, a definition-dependent quantity, e.g., defined as the equally weighted average of the previous trading day's high, low and close prices.

placed order: an order that has been submitted to an exchange and placed in a queue for execution.

placement: the initial stage in the money laundering process, whereby illegal funds are introduced into the legal economy via fraudulent means.

Porter stemming algorithm: an algorithm for reducing words to their base form (stemming).

portfolio: a collection of assets held by an institution or individual investor.

portfolio diversification: see *diversification*.

portfolio optimization: selecting the best portfolio based on some criterion (e.g., maximizing the Sharpe ratio).

portfolio weights: the relative percentages of the dollar holdings in a portfolio to its total notional value (defined as the total notional value of the long positions plus the total absolute notional value of the short positions).

position: the amount of stock or other security held, expressed in dollars, shares, or some other units, with short positions possibly having negative values depending on a convention used.

position bounds: upper or lower bounds on the dollar holdings of various assets in a portfolio.

predicted class: in machine learning, the outcome predicted by an algorithm.

predictor (a.k.a. predictor variable): in machine learning, an input variable.

premium (for insurance-type products): a periodic payment for insurance coverage, e.g., in a CDS, CDO, etc.

premium (for options): the cost of buying an option.

premium leg: the leg of a CDO corresponding to the CDO premiums, the other leg being the default leg.

prepayment: settling a debt or installment payment before its due date (e.g., mortgage prepayment).

prepayment risk: the main risk to investors in a passthrough MBS whereby homeowners have an option to prepay their mortgages (e.g., by refinancing their mortgages as the interest rates drop).

price-momentum strategy: a momentum strategy where the momentum indicator is based on past returns.

pricing data: historical and real-time data containing prices, trading volumes and related quantities (see *market data*).

pricing model: a model for valuing (pricing) a security or a set of securities.

principal: the amount the debt issuer (borrower) owes the lender at debt maturity.

principal component: for a symmetric square matrix, an eigenvector thereof normalized such that the sum of squares of its components equals 1, with different principal components ordered in the descending order by the corresponding eigenvalues.

principal component analysis (PCA): a mathematical procedure that transforms some number of (typically, correlated) variables into a (typically, smaller) number of uncorrelated variables (principal components), with the first principal component accounting for as much of the variability in the data as possible, and each succeeding principal component accounting for as much of the remaining variability as possible.

probability distribution: a function that provides the probabilities of occurrence of different possible outcomes.

probability measure: a real function valued in the interval between 0 and 1 (0 corresponding to the empty set and 1 corresponding to the entire space) defined on a set of events in a probability space that satisfies the countable additivity property, i.e., simply put, that the probability of a union of disjoint events A and B equals the sum of their probabilities.

protection buyer: a buyer of insurance.

protection seller: a seller of insurance.

protective call (a.k.a. married call, or synthetic put): hedging a short stock position with a long call option position.

protective put (a.k.a. married put, or synthetic call): hedging a long stock position with a long put option position.

publicly traded company (a.k.a. public company): a company whose shares are freely traded on a stock exchange or in over-the-counter markets.

put-call parity: the relationship whereby the payoff of a European call option (with a strike price K and expiration T) minus the payoff of a European put option (on the same underlying and with the same strike and expiration) equals the payoff of a forward contract (on said underlying) with the strike K and expiry T.

put option (a.k.a. put): see *European put option, option.*

quantile: each of the n (approximately) equal parts of a sample (e.g., data sample), where $n > 1$.

quantitative trading: systematic trading strategies based on quantitative analysis and mathematical computations with little to no human intervention outside of developing a strategy (which includes coding it up in a suitable computer language).

quark spread: the analog of the spark spread and the dark spread for nuclear power plants.

quintile: each of the 5 (approximately) equal parts of a sample (e.g., data sample).

R: R Package for Statistical Computing.

R-squared: in a regression, 1 minus a ratio, whose numerator is the sum of squares of the residuals, and whose denominator is the sum of squares of the deviations of the values of the observable variable from their mean value across the data sample.

rally: in financial markets, a period of sustained gains.

rank (for matrices): the maximum number of linearly independent columns of a matrix.

rank (a.k.a. ranking): the position of an element of a set after sorting it according to some criterion (with a prescription for resolving possible ties).

rate: see *interest rate, inflation.*

rating: see *credit rating.*

ratio spread: a type of options strategies.

real estate: tangible immovable assets including land, structures built on it, etc.

real estate investment trust (REIT): a company (often traded on major exchanges and thus allowing investors to take a liquid stake in real estate) that owns, operates or finances income-producing real estate.

real interest rate: interest rate adjusted for inflation.

realized P&L: the P&L on a completed trade, i.e., the P&L resulting from establishing a position and then completely liquidating it.

realized profit: see *realized P&L*.

realized return: historical return.

realized volatility: historical volatility.

rebalancing: changing the holding weights in a portfolio.

recovery rate: the percentage of the principal and accrued interest on defaulted debt that can be recovered.

rectified linear unit (ReLU): the function of x given by $\max(x, 0)$.

reference entities: in a CDS, bonds, loans, names of companies or countries, etc., on which default protection is provided.

regression: see *linear regression*.

regression coefficient: the slope of an independent variable in a linear regression.

regression residuals: the differences between the observed values and the fitted (model predicted) values of the dependent variable in a linear regression.

regression-weighted butterfly: a type of bond butterfly portfolio.

regression weights: the positive weights w_i (which need not equal 1) in the sum of squares $\sum_{i=1}^{N} w_i \, \epsilon_i^2$, whose minimization determines the regression coefficients and regression residuals ϵ_i.

reinvestment risk: the risk that the proceeds (from the coupon payments and/or principal of a bond or similar instrument) would be reinvested at a lower rate than the original investment.

relative momentum: cross-sectional momentum.

relative strength index (RSI): during a specified timeframe, the average gain of the up periods divided by the sum of the average gain of the up periods and the absolute value of the average loss of the down periods.

relative value strategy: a strategy that aims to exploit differences in the prices, returns or rates (e.g., interest rates) of related (by some criterion) securities (e.g., historically correlated stock pairs in pairs trading).

reorganization: a Court-supervised process of restructuring a company's finances in bankruptcy.

reorganization plan: a plan for reorganization of a company in bankruptcy that can be submitted (e.g., by a creditor with the view of obtaining participation in the management of the company) to Court for approval.

replication: a strategy whereby a dynamic portfolio of assets precisely replicates cash flows of another asset or portfolio.

repurchase agreement (a.k.a. REPO or repo): a cash-equivalent asset that provides immediate liquidity at a preset interest rate for a specific period of time in exchange for another asset used as a collateral.

resistance: in technical analysis, the (perceived) price level at which a rising stock price is expected to bounce back down.

retail trader: a non-professional individual trader.

reverse repurchase agreement: a REPO from the standpoint of the lender.

rich stock: a stock that is perceived to be overvalued by some criterion.

risk: the possibility that the realized return will differ from the expected return.

risk-adjusted return: return divided by volatility.

risk arbitrage: see *merger arbitrage*.

risk factor: see *factor*.

risk-free arbitrage: making profit without any risk.

risk-free asset (a.k.a. riskless asset): an asset with a certain future return, e.g., Treasury bills.

risk-free discount factor: a discount factor that uses a risk-free rate for discounting future cash flows.

risk-free probability measure (a.k.a. risk-neutral measure): a theoretical probability measure under which an asset's current price equals its future

expected value discounted by a risk-free rate.

risk-free rate: the rate of return of a risk-free asset, often taken to be the one-month Treasury bill rate.

risk management: identifying, analyzing and mitigating potential risks.

risk model: a mathematical model for estimating risk (e.g., modeling a covariance matrix).

risk premia (same as risk premiums): plural of *risk premium*.

risk premium: the (expected) return in excess of the risk-free rate from an investment.

risk reversal (a.k.a. combo): a type of options strategies.

risk sentiment: investor risk tolerance in response to global economic patterns, whereby when risk is perceived as low (high), investors tend to engage in higher-risk (lower-risk) investments (a.k.a. "risk-on risk-off").

risky duration: a weighted sum (over the payment dates) of the (discounted) differences between the notional (of a CDO tranche or similar) and expected loss for each such date, where each weight is the time from the previous payment date.

roll: in futures contracts, rebalancing futures positions, whereby when the current long (short) futures contract is about to expire, it is sold (covered) and another futures contract with longer expiration is bought (sold).

roll loss (a.k.a. contango loss): in ETNs such as VXX and VXZ consisting of VIX futures portfolios, a decay in their values (when the VIX futures curve is in contango) due to their daily rebalancing required to maintain a constant maturity.

roll value: see *daily roll value*.

roll yield: in commodity futures, positive returns from the roll generated by long (short) positions when the term structure is in backwardation (contango).

rolling down the yield curve (a.k.a. rolling down the curve): a trading strategy that amounts to buying long- or medium-term bonds from the steepest segment of the yield curve (assuming it is upward-sloping) and selling them as they approach maturity.

root mean square error (RMSE): the square root of the mean value of the squares of the differences between the predicted and observed values of a variable.

rotation: see *alpha rotation, sector momentum rotation.*

rung: in a bond ladder portfolio, the bonds of the same maturity.

Russell 3000: a market cap weighted index of the 3,000 largest U.S.-traded stocks by market cap.

S&P 500: a market cap weighted index of the 500 largest U.S. publicly traded companies by market cap.

sample correlation matrix: a correlation matrix for a set of securities computed based on the time series of their historical returns.

sample covariance matrix: a covariance matrix for a set of securities computed based on the time series of their historical returns.

sample variance: a variance computed based on the time series of a security's historical returns.

scale invariance: a function $f(x_i)$ of N variables x_i $(i = 1, \ldots, N)$ is scale invariant if $f(\zeta x_i) = f(x_i)$ for an arbitrary scale factor ζ taking values in a continuous interval (e.g., positive real values).

seagull spread: a type of options strategies.

second-month futures: a futures contract with the nearest expiration after the front-month futures.

sector (in economy): an area of the economy in which businesses share similar products or services.

sector (in industry classification): usually, the least granular level in a multilevel industry classification (e.g., sectors are split into industries, industries are split into sub-industries).

sector momentum rotation: a type of momentum strategy for ETFs.

secured loan: a loan secured with a collateral.

security: in finance, usually a fungible, negotiable financial instrument with

monetary value.

selectivity: a quantitative measure of active management of mutual funds (as well as actively-managed ETFs).

sell-write strategy: shorting stock and writing (selling) a put option against the stock position.

senior mezzanine tranche: the next (by increasing quality) tranche of a CDO after the junior mezzanine tranche.

senior tranche: the next (by increasing quality) tranche of a CDO after the senior mezzanine tranche.

sentiment analysis (a.k.a. opinion mining): the use of natural language processing and other computational techniques to extract information from (electronic) documents (e.g., tweets) pertinent to a security, e.g., for forecasting the direction of its price movements.

sentiment data: the textual data used in sentiment analysis (e.g., the contents of tweets).

Separate Trading of Registered Interest and Principal of Securities (a.k.a. STRIPS): zero-coupon Treasury securities.

serial correlation: a pair-wise correlation between two securities computed based on their time series of historical returns.

serial quantity: a quantity (e.g., mean, standard deviation, etc.) computed serially (i.e., across the time series for each security) as opposed to cross-sectionally (i.e., across a set of securities).

serial regression: a regression where the independent variables are time series (cf. *cross-sectional regression*).

settlement: the fulfillment of the obligations under a futures or forward contract at expiration.

share: a unit of ownership interest in a corporation or financial asset.

shareholder (a.k.a. stockholder): an owner of shares in a company.

shares outstanding: the total number of a company's shares held by all its

shareholders.

Sharpe ratio: (excess) return divided by volatility.

short position (a.k.a. short): selling an asset without owning it by borrowing it from someone else, typically, a brokerage firm.

short-sale (a.k.a. short-selling, or shorting): establishing a short position.

sideways market: when prices remain in a tight range, without clear up or down trends.

sideways strategy: a trading strategy that aims to capitalize on an expected low volatility environment, e.g., by selling volatility.

sigmoid: the function of x given by $1/(1+\exp(-x))$.

signal: a trading signal, e.g., to buy (buy signal) or sell (sell signal) a security.

simple moving average (SMA): a moving average without suppressing past contributions (cf. *exponential moving average*).

simple moving standard deviation: a moving standard deviation without suppressing past contributions (cf. *exponential moving standard deviation*).

single-name CDS: a CDS on a single reference entity.

single-stock option: an option on a single underlying stock (as opposed to, e.g., an option on a portfolio of stocks such as an index).

single-stock strategy: a trading strategy that derives a trading signal for any given stock using data for only that stock and no other stocks.

skewness: a measure of asymmetry in a probability distribution, defined as the mean value of the cubic power of the deviation from the mean divided by the cubic power of the standard deviation.

skewness premium: in commodity futures, an empirical occurrence whereby future expected returns tend to be negatively correlated with the skewness of historical returns.

skip period: in price-momentum and similar strategies, the period (usually, the last 1 month) skipped before the formation period (usually the last 12 months prior to the skip period).

slippage: the difference between the price at which an (initial) order is placed (or expected/hoped to be executed) and at which it is filled (including after cancel-replacing the initial order when chasing the bid or ask with buy or sell limit orders, respectively), sometimes averaged over multiple orders (e.g., when a large order is broken up into smaller ones).

smart order flow (a.k.a. toxic order flow): order flow based on some predictive expected return.

SMB (a.k.a. Small minus Big): see *Fama-French factors*.

social media sentiment: the sentiment on stocks or other securities extracted from social media posts or messages (e.g., on Twitter).

softmax: the function $\exp(x_i)/\sum_{j=1}^{N}\exp(x_j)$ of an N-vector x_i $(i = 1, \ldots, N)$.

sorting: organizing a set in an ascending or descending order based on some quantity (with a prescription for resolving possible ties).

source code (a.k.a. code): computer code written in some computer programming language.

sovereign risk: the risk that a government could default on its debt (sovereign debt, e.g., government-issued bonds) or other obligations, or that changes in a central bank's policy may adversely affect FX contracts.

spark spread: the difference between the wholesale price of electricity and the price of natural gas required to produce it.

SPDR Trust (ticker SPY): an S&P 500 tracking EFT.

specialist system: a (largely) human-controlled and operated market-making system at NYSE prior to switching to (mostly) electronic trading.

specific risk (a.k.a. idiosyncratic risk): see *non-systematic risk*.

speculative asset: an asset with little to no intrinsic value.

speculative bubble: see *bubble*.

speculator: a market participant attempting to profit from a security's price movement (cf. *hedger*).

spike: a relatively large upward or downward movement of a security's price in a short period of time.

split (a.k.a. stock split): a corporate action in which a company divides its existing shares into multiple shares (forward stock split) or combines multiple shares into one (reverse stock split).

spot (a.k.a. spot price, or spot value): the current price of an asset.

spot FX rate (a.k.a. FX spot rate, or spot rate): the current FX rate.

spread: the difference between two quantities, or a portfolio consisting of two (or more) legs comprised of the same type of assets different only by one or more specific quantities (e.g., strike price, or strike price and expiration).

standard deviation: the square root of the variance.

standardized unexpected earnings (SUE): a ratio, whose numerator (unexpected earnings) is the difference between the most recently announced quarterly earnings per share and those announced 4 quarters ago, and whose denominator is the standard deviation of the unexpected earnings over the last 8 quarters.

state variable: one of a set of variables (which may or may not be observable) used to describe a dynamical system.

statistical arbitrage (a.k.a. Stat Arb, or StatArb): typically, shorter-horizon trading strategies with sizable trading universes (e.g., a few thousand stocks) based on complex cross-sectional (and serial) statistical mean-reversion signals.

statistical industry classification: a multilevel clustering of companies based on purely statistical techniques, e.g., distance-based clustering of the companies' returns (cf. *fundamental industry classification*).

statistical risk model: a risk model built using only the pricing data (e.g., using principal components of the sample correlation matrix of stock returns), without any reference to fundamental data (including any fundamental industry classification).

steepener: a yield curve spread bond strategy.

stemming: reducing a word to its base form, the part of a word that is common to all its inflected variants.

stemming algorithm: see *Porter stemming algorithm.*

stochastic dynamics: see *stochastic process.*

stochastic gradient descent (SGD): an iterative method for optimizing a differentiable objective function.

stochastic process: a collection of random variables that change with time.

stock: a security representing fractional ownership in a corporation.

stock merger: a merger where each share of the target company is swapped for some number (which can be fractional) of the acquirer company's shares.

stop-loss price: the price of an asset at which a position in said asset is (automatically) liquidated.

stop-word: the most commonly used words in a language (e.g., "the", "is", "in", "which", etc.) that add no value in a particular context and are ignored by a natural language processing tool.

straddle: an option trading strategy.

strangle: an option trading strategy.

strap: an option trading strategy.

strategy: see *trading strategy.*

strike price (a.k.a. strike): the price at which a derivative contract can be exercised.

strip: an option trading strategy.

structured asset: a complexly structured (debt) instrument such as a CDO or ABS.

style risk factor (a.k.a. style factor): risk factors such as value, growth, size, momentum, liquidity and volatility.

sub-industry (in industry classification): usually, a subgroup of companies within the same industry grouped together based on a more granular criterion.

super senior tranche: the highest quality tranche of a CDO.

support: in technical analysis, the (perceived) price level at which a falling stock price is expected to bounce back up.

support and resistance strategy: a technical analysis strategy based on support and resistance.

support vector machine (SVM): in machine learning, a type of supervised learning models.

swap (a.k.a. swap agreement, or swap contract): a derivative contract through which two parties exchange financial instruments.

swap spread: the difference between the fixed rate of an interest rate swap and the yield on a Treasury security with a similar maturity.

swap-spread arbitrage: a dollar-neutral strategy consisting of a long (short) position in an interest rate swap and a short (long) position in a Treasury bond with the same maturity as the swap.

synthetic security (a.k.a. synthetic): a financial instrument created (via a portfolio of assets) to replicate (or approximately reproduce) the same cash flows as another security (e.g., synthetic put, call, straddle, forward, futures, etc.).

systematic approach: methodical, rules-based trading strategies with well-defined trade goals and risk controls (as opposed to, e.g., analysts' subjective opinions).

systematic macro: non-discretionary, systematic macro trading strategies.

systematic risk: non-diversifiable risk inherent to the entire market or its segment, such as exposure to broad market movements, which cannot be diversified away in long-only portfolios, but can nonetheless be substantially reduced or even essentially eliminated in long-short (e.g., dollar-neutral) portfolios.

tactical asset allocation: a dynamic investment strategy that actively adjusts a portfolio's asset allocation weights.

tanh: hyperbolic tangent.

target company: the company chosen by the acquirer company for a potential corporate merger or acquisition.

target variable: in machine learning, the variable whose values are to be modeled and predicted.

tax arbitrage: profiting from differences in how income, capital gains, transactions, etc., are taxed.

tax credit: see *dividend imputation*.

tax-exempt municipal bonds: e.g., municipal bonds that are not subject to Federal income taxes (on the interest earned) in the U.S.

tax shield: the reduction in income taxes that results from taking an allowable deduction from taxable income.

technical analysis: a methodology for forecasting the direction of prices using historical market data, primarily price and volume (cf. *fundamental analysis*).

technical indicator: a mathematical quantity used in technical analysis.

tercile: each of the 3 (approximately) equal parts of a sample (e.g., data sample).

term spread: an interest rate spread corresponding to two different maturities.

term structure (in futures): the dependence of futures prices on time to maturity.

term structure (in interest rates): see *yield curve*.

Theta: the first derivative of the value of a derivative asset (e.g., option) w.r.t. time.

Theta-decay: the time decay of an option's (or other asset's) value as time nears the expiration.

ticker (a.k.a. ticker symbol): a short character string representing a particular publicly traded security.

time series: a series of data points indexed in time order, i.e., labeled by time values.

time-to-maturity (TTM): time left before an option expires.

TIPS-Treasury arbitrage: a trading strategy consisting of selling a T-bond and offsetting the short position by a lower-cost replicating portfolio consisting of TIPS, inflation swaps and STRIPS.

Treasury Inflation-Protected Securities (TIPS): Treasury securities that pay semiannual fixed coupons at a fixed rate, but the coupon payments (and principal) are adjusted based on inflation.

tracking error: the square root of the variance of the differences between the returns of a portfolio and those of the benchmark or index said portfolio is meant to mimic or beat.

tracking ETF: an ETF that tracks an index.

trader: a person who buys and sells goods, currency, stocks, commodities, etc.

trading bounds: upper or lower bounds on the dollar amounts of allowed trades for various assets in a portfolio, when establishing, rebalancing or liquidating.

trading on economic announcements: a trading strategy that buys stocks on important announcement days, such as FOMC announcements, while holding risk-free assets on other days.

trading costs (a.k.a. transaction costs): costs associated with trading securities, including (as applicable) exchange fees, brokerage fees, SEC fees, slippage, etc.

trading days: usually, the days on which NYSE is open.

trading rule: a set of buy and sell instructions, with the quantities of the assets to be bought or sold.

trading signal: see *signal*.

trading strategy: a set of instructions to achieve certain asset holdings by some predefined times $t_1, t_2, \ldots$, which holdings can (but need not) be null at one or more of these times.

trading universe (a.k.a. universe): the tickers of stocks (or other securi-

ties) in a trading portfolio.

traditional assets: stocks, bonds, cash, real estate and, in some cases, also currencies and commodities.

training: in machine learning, fixing free parameters in an algorithm using training data.

training data (a.k.a. training dataset): in machine learning, a set of input-output pairs known in advance, which are used to train a machine learning algorithm.

training period: in machine learning, the period spanned by the training data when it is a time series.

tranche: see *CDO tranche*.

Treasuries: Treasury securities.

Treasury: the U.S. Department of Treasury.

Treasury bill (a.k.a. T-bill): a short-term debt obligation issued by the U.S. Treasury with maturity under 1 year.

Treasury bond (a.k.a. T-bond): a bond issued by the U.S. Treasury with maturity of more than 10 years.

Treasury curve: the yield curve of Treasury securities.

Treasury ETF: a tracking ETF for an index composed of U.S. government debt obligations.

Treasury note (a.k.a. T-note): a debt security issued by the U.S. Treasury with maturity between 1 and 10 years.

tree boosting: a machine learning technique.

trend: the general direction of a market or asset's price, essentially, momentum.

trend following: a trading strategy that aims to capture gains from an asset's momentum in a particular direction.

triangular arbitrage: see *FX triangular arbitrage*.

Twitter sentiment: the sentiment on stocks or other securities extracted from tweets.

U.S. regions: East, Mid-West, South and West.

unadjusted quantity: price or volume unadjusted for splits or dividends.

uncompounded rate: an interest rate applied to the principal during some period without any compounding.

underlying: underlying instrument (e.g., stock in a single-stock option).

underreaction: in financial markets, an insufficient response to news, as some market participants tend to be conservative and rely too much on their prior beliefs.

unexpected earnings: see *standardized unexpected earnings*.

value: a factor based on the book-to-price (B/P) ratio.

value strategy: buying high value (high B/P ratio) stocks and selling low value (low B/P ratio) stocks.

variable coupon bond: see *floating coupon bond*.

variable rate: see *floating interest rate*.

variance: a mean value of the squares of the deviations of the values of a quantity from their mean value.

variance swap: a derivative contract whose payoff at maturity is a product of a preset coefficient (variance notional) times the difference between the realized variance at maturity of the underlying and the preset variance strike.

Vega: the first derivative of the value of a derivative asset (e.g., option) w.r.t. the implied volatility of the underlying asset.

vertical spread: an option strategy that involves all identical put or all identical call options with the exception of their strike prices.

volatility: a statistical measure of the dispersion of returns for a security or market index, which is expressed via the standard deviation or variance of said returns.

VIX: CBOE Volatility Index, a.k.a. the "uncertainty index" or the "fear gauge index".

volatility carry strategy: a trading strategy consisting of shorting VXX and offsetting the short position with long VXZ (see *volatility ETN*), generally with a non-unit hedge ratio.

volatility ETN: an ETN that tracks VIX, e.g., VXX or VXZ.

volatility index: an index (e.g., VIX) that measures the market's expectation of future (30-day for VIX) volatility based on implied volatilities of the underlying instruments (the S&P 500 stocks for VIX).

volatility risk premium: an empirical occurrence that implied volatility tends to be higher than realized volatility most of the time.

volatility skew: an empirical occurrence whereby, with all else being equal, the implied volatility for put options is higher than for call options.

volatility strategy: a trading strategy that aims to capitalize on an expected high volatility environment, e.g., by buying volatility.

volatility targeting strategy: a trading strategy that aims to maintain a constant volatility level (volatility target, or target volatility) by rebalancing between a risky asset and a risk-free asset.

volume: the number of shares or contracts traded in a security during some period.

watt: a unit of power in the International System of Units (SI).

weather derivative: a derivative (e.g., option or futures) on a synthetic weather index.

weather index: a synthetic index usually based on temperature, using, e.g., cooling-degree-days (CDD) and heating-degree-days (HDD).

weather risk: a risk stemming from businesses and sectors of the economy being affected by weather conditions.

weighted average: for N values x_i ($i = 1, \ldots, N$), the weighted mean given by $\frac{1}{N} \sum_{i=1}^{N} w_i \, x_i$, where w_i are the weights.

weighted regression: a linear regression with nonuniform regression weights.

weighting scheme: assigning portfolio weights according to some rule, e.g., by suppressing contributions of volatile stocks.

weights (in ANN): in an artificial neural network, the coefficients of the inputs in the argument of an activation function.

weights (in portfolios): see *portfolio weights*.

Whittaker-Henderson method: see *Hodrick-Prescott filter*.

wing: one of the 2 peripheral (by maturity in bond portfolios, and by strike price in option portfolios) legs of a butterfly portfolio.

winners: stocks or other assets in a portfolio or trading universe that outperform based on some criterion (benchmark).

word (a.k.a. keyword): a keyword in a learning vocabulary.

year-on-year (YoY) inflation: annual inflation (cf. *cumulative inflation*).

year-on-year inflation swap: an inflation swap that references annual inflation (cf. *zero-coupon swap*).

yield: see *bond yield*.

yield curve (a.k.a. term structure): the dependence of interest rates or bond yields on maturities.

yield curve spread: the spread between shorter and longer maturity bonds on the yield curve.

yield curve spread strategy: a bond strategy that makes a bet on the yield curve spread (flattener or steepener).

zero-cost strategy: a dollar-neutral strategy.

zero-coupon bond: see *discount bond*.

zero-coupon inflation swap: an inflation swap that has only one cash flow at maturity and references the cumulative inflation over the life of the swap (cf. *year-on-year inflation swap*).

Acronyms

ABS: asset-backed security.

ADDV: average daily dollar volume.

ANN: artificial neural network.

ATM: at-the-money.

B/P: book-to-price.

BA: banker's acceptance.

BICS: Bloomberg Industry Classification System.

bps: basis point.

BTC: Bitcoin.

Btu: British thermal unit.

CA: commodity allocation percentage.

CBOE: Chicago Board Options Exchange.

CD: certificate of deposit.

CDD: cooling-degree-days.

CDO: collateralized debt obligation.

CDS: credit default swap.

CFTC: U.S. Commodity Futures Trading Commission.

CI: core inflation.

CIRP: Covered Interest Rate Parity.

CME: Chicago Mercantile Exchange.

COT: Commitments of Traders.

CPI: Consumer Price Index.

CPS: cents-per-share.

CTA: commodity trading advisor.

DJIA: Dow Jones Industrial Average.

EMA: exponential moving average.

EMSD: exponential moving standard deviation.

ETF: exchange-traded fund.

ETH: Ethereum.

ETN: exchange-traded note.

EUR: euro.

FOMC: Federal Open Market Committee.

FX: foreign exchange.

GDP: Gross Domestic Product.

GICS: Global Industry Classification Standard.

HDD: heating-degree-days.

HFT: high frequency trading.

HI: headline inflation.

HMD: healthy-minus-distressed.

HML: High minus Low.

HP: hedging pressure; Hodrick-Prescott.

IBS: internal bar strength.

ITM: in-the-money.

JPY: Japanese Yen.

LETF: leveraged (inverse) ETF.

LIBOR: London Interbank Offer Rate.

M&A: mergers and acquisitions.

MA: moving average.

ML: machine learning.

MBS: mortgage-backed security.

MBtu: 1,000 Btu.

MKT: market (excess) return.

MMBtu: 1,000,000 Btu.

MOM: Carhart's momentum factor.

MSA: metropolitan statistical area.

MTM: mark-to-market.

Mwh: Megawatt hour.

NYSE: New York Stock Exchange.

OAS: option adjusted spread.

OTM: out-of-the-money.

P&L: profit(s) and loss(es).

P2P: peer-to-peer.

PCA: principal component analysis.

REIT: real estate investment trust.

ReLU: rectified linear unit.

REPO/repo: repurchase agreement.

RMSE: root mean square error.

RSI: relative strength index.

S&P: Standard and Poor's.

SIC: Standard Industrial Classification.

SMA: simple moving average.

SMB: Small minus Big.

SGD: stochastic gradient descent.

SS: sum of squares.

StatArb: statistical arbitrage.

STRIPS: Separate Trading of Registered Interest and Principal of Securities.

SUE: standardized unexpected earnings.

SVM: support vector machine.

TTM: time-to-maturity.

TIPS: Treasury Inflation-Protected Securities.

UIRP: Uncovered Interest Rate Parity.

USD: U.S. dollar.

VAR: vector autoregressive model.

VWAP: volume-weighted average price.

YoY: year-on-year.

Some Math Notations

iff if and only if.

max (min) maximum (minimum).

floor(x) the largest integer less than or equal x.

ceiling(x) the smallest integer greater than or equal x.

$(x)^+$ $\max(x, 0)$.

sign(x) sign of x, defined as: $+1$ if $x > 0$; -1 if $x < 0$; 0 if $x = 0$.

$|x|$ absolute value of x if x is a real number.

rank(x_i) rank of x_i when N values x_i ($i = 1, \ldots, N$) are sorted in the ascending order.

$\exp(x)$ or e^x natural exponent of x.

$\ln(x)$ natural log of x.

$\sum_{i=1}^N x_i$ sum of N values x_i ($i = 1, \ldots, N$).

$\prod_{i=1}^N x_i$ product of N values x_i ($i = 1, \ldots, N$).

$A|_{B=b}$ (or $A|_b$) the value of A when some quantity B it implicitly depends on (usually evident from the context) takes value b.

$f(x) \to \min$ ($\max$) minimizing (maximizing) $f(x)$ w.r.t. x (where x can, e.g., be an N-vector x_i, $i = 1, \ldots, N$).

$\text{argmax}_z\ f(z)$ the value of z for which $f(z)$ is maximized.

$\partial f/\partial x$ the first partial derivative of the function f (which may depend on variables other than x) w.r.t. x.

$\partial^2 f/\partial x^2$ the second partial derivative of the function f (which may depend on variables other than x) w.r.t. x.

$G : A \mapsto B$ G is a map from set A to set B.

$A \subset B$ set A is a subset of set B.

$\{i|f(i) = a\}$ the set of values of i such that the condition $f(i) = a$ is satisfied.

$\min(i : f(i) > a)$ the minimum value of i such that the condition $f(i) > a$ is satisfied.

$i \in J$ i is an element of set J.

$|J|$ the number of elements of J if J is a finite set.

δ_{AB} (or $\delta_{A,B}$) 1 if $A = B$; otherwise, 0 (Kronecker delta).

$\mathrm{diag}(x_i)$ diagonal $N \times N$ matrix with x_i $(i = 1, \ldots, N)$ on its diagonal.

A^T transpose of matrix A.

A^{-1} inverse of matrix A.

$E_t(A)$ expected value of A at time t.

$dX(t)$ an infinitesimal increment of a continuous process $X(t)$.

dt an infinitesimal increment of time t.

$P(A|B)$ conditional probability of A occurring assuming B is true.

Explanatory Comments for Index

In the index entries, plural in many (but not all) cases is reduced to singular (so, e.g., "commodity" also includes "commodities"). Parentheses contain acronyms or definitions, and in some (but not all) cases both versions are present in the main text. Most (but not all) index entries with commas, i.e., "*noun, adjective*", correspond to text entries such that the precise string "*adjective noun*" is not directly present in the text, but is present indirectly (e.g., as "*adjective (...) noun*") or contextually.

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