151 Trading Strategies

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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.

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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 Services; and Editor, *Journal of Asset Management*

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

Author Biographies

Zura Kakushadze received his Ph.D. in theoretical physics from Cornell University, USA at 23, was a Postdoctoral Fellow at Harvard University, USA and an Assistant Professor at C.N. Yang Institute for Theoretical Physics at Stony Brook University, USA. He received an Alfred P. Sloan Foundation Fellowship in 2001. After expanding into quantitative finance, he was a Director at RBC Capital Markets, Managing Director at WorldQuant, Executive Vice President and substantial shareholder at Revere Data (now part of FactSet), and Adjunct Professor at the University of Connecticut, USA. Currently he is the President and CEO of Quantigic® Solutions and a Full Professor at Free University of Tbilisi, Georgia. He has over 17 years of hands-on experience in quantitative trading and finance, 130+ publications in physics, finance, cancer research and other fields, 3,400+ citations and *h*-index 30+, 170,000+ downloads on SSRN, and over a quarter million followers on LinkedIn.

Juan Andrés Serur holds a Master's Degree in Finance from the University of CEMA, Argentina. With more than 6 years of experience in trading in the stock market, he currently works as a quantitative analyst and strategist in an Argentine quantitative asset management firm and as a financial consultant for large corporations. In addition, he serves as the Academic Secretary of the Master of Finance Program at the University of CEMA, where he teaches undergraduate and postgraduate computational finance courses as an Assistant Professor. In 2016 he won the First Prize in an Argentine Capital Markets Simulation Challenge for Universities and Professional Institutions.

Preface (by Zura Kakushadze)

The purpose of this "post-factum" Preface is to give some history, which sheds light on why we (the authors) have decided to make this book, which has been published in hardcover (and as an e-book),[4] into a freely downloadable PDF e-book on SSRN.

In December of 2015 I posted the paper "101 Formulaic Alphas" on SSRN [Kakushadze, 2016], which provides explicit formulas (that are also computer source code) for 101 real-life formulaic quantitative trading alphas. That paper was a hit – in hindsight, perhaps unsurprisingly, considering how secretive quant trading is.

So, at some point down the road, a light bulb went on in my head and I got this seemingly "crazy" idea to write a paper entitled "101 Trading Strategies", except that this time these 101 strategies would be spread across all asset classes (as opposed to equities (StatArb) quant trading alphas as in "101 Formulaic Alphas"). I did not envision this as a book, just as a paper, maybe 100+ pages long, 1 page per strategy on average, plus overhead (introduction, references, etc.), something publishable in a journal (at least online). I also thought it would be both fun and efficient to get around 10-12 coauthors together, each would contribute about 10 strategies in one or two asset classes according to their fields of expertise, so the project would go faster. So, I pinged my contacts by email and posted several posts in the LinkedIn feed and groups saying that I was looking for collaborators for this project. I got a rather decent number of responses, some evidently were not serious, but some were.

However, once I outlined in more detail what I had in mind for this project – I had a written plan – apparently people realized that this would not be a cakewalk, and most disappeared. As it turned out, the only person who was truly serious about this project was Juan Andrés Serur, a young professor from Buenos Aires, Argentina, whom I had never even met in person. There were a lot of challenges along the way (including that Juan had never worked on a project of this magnitude and was learning on the job, so to speak). But at the end we got through it. Except that we did not have just 100+ pages with 101 strategies but over 350 pages with around 160-170 strategies (depending on how one counts). This was not publishable in any journal, by any stretch. This project basically had taken on a life of its own and turned into... a book. So, we discussed it and decided to publish it as such.

Publishing a quant trading/finance book such as "151 Trading Strategies" is not a very rewarding business (at least financially), for several reasons. First, the target audience is rather limited because of the highly technical nature of the material. In my original exploratory call with them, the publisher mentioned that books like this sell around 1,000 copies total. This was consistent with what I was told by someone who is well-known in the field and had published 5 quant trading/finance books over the years, which had sold around 5,000 copies altogether. Second, if the book is published by a major publisher, the authors get dismal royalties, usually in the 8-12% range, which can go to around 20% if the book sells better than

[4] 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.

expected. At $60-$70 for a hardcover, your book has to sell 100,000+ copies for you to make any decent money so it is a least somewhat commensurate with the time you spend on writing the book – this book took about 9 months to write, not including the time I spent on it before drafting started (conceiving it, looking for coauthors, etc.) or the time spent dealing with the publisher, advertising it, etc. Third, this particular publisher does not publish paperbacks as a matter of some policy I do not comprehend, and when the price is set around $60-$70 for a hardcover, the pool of potential buyers is dramatically reduced compared with a $20-$30 price point a paperback would have. Fourth, there are plenty of people working in quant trading/finance who can easily afford $60-$70, but many of these people – not to offend anyone – would rather download a pirated PDF copy from the internet... Fifth, the publisher's business model appears to be immune to the fact that they cannot make much money from hardcover sales. Instead, their business model appears to hinge on e-book downloads through their existing (institutional) subscriptions: a subscriber, who pays a subscription fee, can freely download any book from the publisher's portfolio. So, the success of a book is measured by e-book downloads by subscribers, not by hardcover sales, and the authors do not get paid per download, they only get paid a very symbolic (mildly put) flat fee irrespective of the number of such downloads. The bottom line is that there is no money to be made in this business for the authors. We were well-aware of this from the get-go. We did not publish this book for money – originally, it was going to be a paper.

What is worse though is that, unlike in the olden days when editors would read every word of your manuscript and mark it up so it could be improved, etc., nowadays there appears to be little to no editorial support. We wrote the manuscript in LaTeX (as there are over 550 elevated equations in the book, not counting inline math), we created the index ourselves (which is a major pain and very time-consuming, if done right; in fact, it is probably the single worst part of writing a book), and proofread the manuscript several times to the point where upon the final proofreading right before printing we found only 5 minor typos attributable to our original manuscript. The bottom line is that we spent a lot of time perfecting our manuscript and it was very much print-ready. However, things got really messy on the publisher's end.

The nightmare started with the book cover. The publisher ask me if I had any concrete ideas for how I wanted the cover designed, and if I had a specific cover image in mind and to feel free to send along some images from Getty and Alamy (the image providers the publisher uses). I was taken aback. They keep almost all the profits and they ask me for the cover design? If we have to design our own cover, then we might as self-well publish and keep most royalties. I told them to design the cover professionally, as this was their responsibility. Their so-called "designs" they forwarded were highly unimpressive (just really super-minimalist – mildly put). So, I ended up designing the cover myself, including picking the cover image from the library of thousands of available images, placing the title and author names on the cover, etc. Their "design team" used my cover design and the only "substantial" change they made was changing the color of the title fonts to (in my humble opinion) suboptimal white – the publisher said they could not accommodate the color I suggested. So, imagine how appalled and taken aback I was when in the ready-to-publish final book version, on the copyright page, they put some name for the cover design credit, and did not even mention mine. They said the cover design "is theirs", apparently referring to their "design team". This was just factually false. But we did not wish to appear "difficult" or "unaccommodating", so we let this go.

However, the nightmare continued with author biographies on an inside flap of the dust jacket. They asked us to provide our headshots. We did. At least three times they produced the author biographies with one of the headshots sizably larger than the other, even though we provided identically sized headshots. Worse yet, they claimed that the headshots on the dust jacket were the same size when they clearly were not. So, again, not to appear "difficult" or "unaccommodating", having wasted an inordinate amount of time on this, we let them leave our headshots out of the inside flap as their "design team" either could not or would not get them right.

Little did we know that this was only the tip of the iceberg. When we finally (and belatedly) received the proofs from the publisher, we found over 100 typos introduced by the publisher's typesetters in most incomprehensible ways. Worse yet, the one inadvertent grammar typo we did have in our original manuscript (along with four other, more subtle, non-grammar typos) was not fixed. It was painfully evident that they did not proofread the manuscript very carefully – them creating 100+ unfathomable typos speaks volumes. So, we spent countless additional hours fixing their typos, and it took more than one round of revisions for them to get it right. In hindsight, this should come as no surprise: as many other publishers, they apparently outsource typesetting, copyediting, cover design, etc., to a developing country, and I highly doubt that, e.g., the English proficiency on the other end of this outsourcing process is top-notch. It is the all-familiar and prevalent sad story: English-language books are produced by people whose first language is not English.

Finally, the book was online. However, the nightmare continued. There is an appendix in the book with computer source code and a lengthy discussion. This appendix was just another chapter in the book and was not supposed to be a part of the free preview of the book, which we expressly discussed and agreed on with the publisher in writing to be limited to the first two chapters. Yet, they included the appendix in the back matter of the book, which is freely downloadable from the publisher's website along with the front matter. When I pointed this out to the publisher, their reply was that, for them to redo the files, it would delay the release of the book accordingly (and, based on prior history, that meant weeks, if not longer). This was already after multiple delays on the publisher's end. So, once again, not to appear "difficult" or "unaccommodating", we let this go and the appendix stayed in the freely-downloadable back matter. Speaking of which, while in our original manuscript all references were in one place, at the end, in the published version the references were cited at the end of each chapter. However, the publisher – for the reasons we do not comprehend – also kept the full list of references in the freely-downloadable back matter. While in the modular (where all chapters, front matter and back matter have separate PDF files) electronic e-book version this is not a big deal, they actually also included these duplicate references in the back matter in the printed version, which substantially (and artificially) increased its number of pages.

But there is more. One would imagine that their production team would do some basic quality control post-production. Months later we found out that the Kindle version on Amazon was all messed up, with equations not displaying properly, etc. The publisher claimed that they provided correct files to Amazon and that the problem was on Amazon's end. It took them several weeks to fix this issue, and the fix was a "hack": they replaced the Kindle version with the so-called "replica" version, which is just a replica of the PDF. Anyone can easily create a "replica" version from a PDF using Kindle Create – this does not take a leading publisher. Furthermore, the Kindle preview version displays material substantially outside of the preview material we agreed on. But then again, who cares about the authors?

Nor did the publisher seem to care much about the apparent pirated versions of the book PDF appearing on various websites. Basically, it was unclear what, if anything, the publisher was doing for the book. Their entire marketing effort was apparently limited to whopping two tweets they sent when the book was published. Essentially all the marketing efforts came from me promoting the book on LinkedIn (where I have over quarter million followers) by posting links to the preview version then-available on SSRN and the full version/hardcover on the publisher's websites.

Perhaps most unfathomably, not only did the publisher apparently did not do much to protect the book from pirated copies being available on the internet, or to promote the book, they outright refused to refute a factually false and defamatory "review" an anonymous purchaser placed on Amazon. E.g., that review falsely claims that "there is only a tiny paragraph (no more than 10 lines), very general, on each strategy and then close to 10 pages of book references after each strategy." This is factually false: there are not "10 pages of book references after each strategy". There are references after each chapter (not strategy or section) pursuant to the publisher's own formatting (see above). The review also falsely claims that "A 10 line description of a very general strategy, no math, no backrest, no optimization." Again, this is factually false: as the reader can readily see, the book has over 550 elevated equations (not counting lots of math embedded in the text), the source code for backtesting in Appendix A, strategies involving optimization, 900+ glossary terms, acronyms and math definitions, etc. Furthermore, simpler strategies have concise (but precise) descriptions, while others span pages, not "10 lines", contrary to what the review falsely claims. The review also complains about the number of references in the book. The book description on Amazon (as well as the publisher's websites) expressly states that there are around 2,000 bibliographic references in the book, one of whose aims is to serve as a reference guide into (and essentially an encyclopedia of) trading strategies (which is also stated in the Editorial Reviews of the book). Therefore, the anonymous reviewer was well aware of this before purchasing the book. The review further falsely claims: "And then, as if it were not enough, at the end of the book the author recaps all the references one more time." The review is expressly attacking "the author" of the book, even though, as mentioned above, the specific formatting of the references (whereby the references pertinent to each chapter are included after each chapter, and all references are also included in the back matter, which is freely downloadable from the publisher's website) was performed by the publisher, not by the authors. Our original manuscript has references only at the end. Again, as mentioned above, why the publisher duplicated the references both after the chapters and in the back matter is not something we understand, and it is not something we did or had control over, contrary to the anonymous reviewer's factually false and defamatory statements.

When we discovered the aforesaid factually false and defamatory review on Amazon, we contacted the publisher and asked them, at the minimum to put a comment on the review refuting its factually false statements, and also to contact Amazon to remove the review (as under Amazon's policies, defamatory reviews are not allowed). To our bewilderment, the publisher suggested that we use our contacts to generate positive reviews on Amazon to counteract that negative review. Incredible, isn't it?

To be clear, having over a quarter million followers on LinkedIn and putting lots of content out there on social media, I have had my share of haters. And one thing I have learned is that there is some truth to the common expression "haters make us famous". When you write a paper or a book or anything else you stick your neck out with, it comes with the territory: some will love it, some will hate it, and some will not care. I write things for the "some-will-love-it" demographic and I do not care about the rest. However, there is a big difference between someone expressing a negative opinion about what you have written – this is perfectly acceptable, we live in a free country with freedom of speech – and someone making factually false and defamatory statements, which is not acceptable. And when you write a book and grant the publisher all kinds of rights for the book, it falls onto the publisher to protect its integrity and reputation, as the publisher owns the rights to the book.

There is a lesson to be learned from all this. That a large publisher will do little to nothing to protect the integrity and reputation of the book or its authors (especially if it involves a potential headache with Amazon) or to promote the book. So, as an author, you do all the hard work, and your publisher just takes over your sweat-and-blood creation, makes money from it, while you do all the work promoting the book, with little to no support from the publisher, including protecting the book from, e.g., being pirated on the internet, defamed, etc. Is this fair? Absolutely not!

So, we have terminated the publishing agreement and are making our work free for everyone to download and benefit from the knowledge we have compiled in this now-free e-book. We hope you enjoy it and thanks for reading our book and our story, which hopefully will also be useful to other authors contemplating publishing a book. Consider this. Without real editorial support, when you have to design the book cover, deal with a large number of typos introduced by the typesetters, etc., is publishing with a big-name publisher all that different from "vanity publishing"?

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1 Introduction and Summary

A trading strategy can be defined as a set of instructions to achieve certain asset holdings by some predefined times $t_1, t_2, \dots$, 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,[5] 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)[6] 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.[7]

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).[8] So, we hope you enjoy!

[5] 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].

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

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

[8] 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);[9] 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).[10] While maintaining the long stock position, the trader can generate income by periodically selling OTM call options. We have:[11]

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

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

[9] H is the net debit for all bought option premia less the net credit for all sold option premia.

[10] This is related to put-call parity (see, e.g., [Stoll, 1969], [Hull, 2012]).

[11] 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:[12]

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

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:[13]

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

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:[14]

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

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

[12] 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].

[13] 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].

[14] 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:[15]

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

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:

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

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:

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

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

[15] 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:

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

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:[16]

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

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:

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

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

[16] 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.[17] 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).[18] 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:

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

[17] 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].
[18] 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:[19]

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

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).[20] This adjusts the trader's outlook from bearish (bear put spread) to conservatively bearish or even non-directional (with an

[19] 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].

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

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

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

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:[21]

$$
\begin{aligned}
&P_{max} = V - D && (73)\\
&L_{max} = D && (74)
\end{aligned}
$$

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:

$$
\begin{aligned}
&P_{max} = V - D && (75)\\
&L_{max} = D && (76)
\end{aligned}
$$

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

[21] 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[22]:

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

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

[22] 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 $D > K_2 - K_1$):[23]

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

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

[23] 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:[24]

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

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.[25] We have (assuming $S_0 \geq K$ and $D > S_0 - K$):

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

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 $D > K - S_0$):

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

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

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

[25] 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:[26]

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

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:[27]

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

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

[27] 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:[28]

$$f_T = N_L \times (S_T - K_2)^+ - N_S \times (S_T - K_1)^+ - H \tag{158}$$

$$S_{*down} = K_2 + H/N_L, \quad H > 0 \tag{159}$$

$$S_{*up} = (N_S \times K_1 - N_L \times K_2 - H)/(N_S - N_L) \tag{160}$$

$$P_{max} = N_L \times (K_1 - K_2) - H \tag{161}$$

$$L_{max} = \text{unlimited} \tag{162}$$

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:

$$f_T = N_L \times (K_2 - S_T)^+ - N_S \times (K_1 - S_T)^+ - H \tag{163}$$

$$S_{*up} = K_2 - H/N_L, \quad H > 0 \tag{164}$$

$$S_{*down} = (N_S \times K_1 - N_L \times K_2 + H)/(N_S - N_L) \tag{165}$$

$$P_{max} = N_L \times (K_2 - K_1) - H \tag{166}$$

$$L_{max} = N_S \times K_1 - N_L \times K_2 + H \tag{167}$$

[28] 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:[29]

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

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:

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

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:

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

[29] 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 $S_{*up} = K_3 - H$):[30]

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

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:

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

[30] 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:

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

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:

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

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:

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

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

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:

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

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:

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

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:

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

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.[31] 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.[32] 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:[33]

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

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

[31] 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].

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

[33] 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:[34]

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

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:

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

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:

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

[34] 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:

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

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

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

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

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

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

3 Stocks

3.1 Strategy: Price-momentum

Empirically, there appears to be certain "inertia" in stock returns known as the momentum effect, whereby future returns are positively correlated with past returns (see, e.g., [Asness, 1994], [Asness *et al*, 2014], [Asness, Moskowitz and Pedersen, 2013], [Grinblatt and Moskowitz, 2004], [Jegadeesh and Titman, 1993]). Let t denote time measured in the units of 1 month, with $t = 0$ corresponding to the most recent time. Let $P_i(t)$ be the time series of prices (fully adjusted for splits and dividends) for the stock labeled by i ($i = 1, \dots, N$, where N is the number of stocks in the trading universe). Let

$$R_i(t) = \frac{P_i(t)}{P_i(t+1)} - 1 \tag{266}$$

$$R_i^{cum} = \frac{P_i(S)}{P_i(S+T)} - 1 \tag{267}$$

$$R_i^{mean} = \frac{1}{T} \sum_{t=S}^{S+T-1} R_i(t) \tag{268}$$

$$R_i^{risk.adj} = \frac{R_i^{mean}}{\sigma_i} \tag{269}$$

$$\sigma_i^2 = \frac{1}{T-1} \sum_{t=S}^{S+T-1} \left(R_i(t) - R_i^{mean}\right)^2 \tag{270}$$

Here: $R_i(t)$ is the monthly return; R_i^{cum} is the cumulative return computed over the T-month "formation period" (usually $T = 12$) skipping the most recent S-month "skip period" (usually $S = 1$);[35] R_i^{mean} is the mean monthly return computed over the formation period; $R_i^{risk.adj}$ is the risk-adjusted mean return over the formation period; and σ_i is the monthly volatility calculated over the formation period.

The price-momentum strategy amounts to buying the best performing stocks and selling the worst performing stocks, where the "performance" is measured by a selection criterion based on R_i^{cum}, R_i^{mean}, $R_i^{risk.adj}$ or some other criterion. E.g., after the stocks are sorted by R_i^{cum} (in the decreasing order), the trader can, e.g., buy stocks in the top decile (winners) and short stocks in the bottom decile (losers).[36] This can be a zero-cost strategy, i.e., the corresponding portfolio is dollar-neutral. Alternatively, a long-only portfolio can be constructed by buying stocks in, e.g., the top decile. Once a portfolio is established at $t = 0$, it is kept unaltered during

[35] Usually, the most recent month is skipped due to an empirically observed mean-reversion (a.k.a. contrarian) effect in monthly returns possibly rooted in liquidity/microstructure issues – see, e.g., [Asness, 1994], [Boudoukh, Richardson and Whitelaw, 1994], [Grinblatt and Moskowitz, 2004], [Jegadeesh, 1990], [Lo and MacKinlay, 1990].

[36] There is some degree of arbitrariness in defining winners and losers.

a predefined "holding period",[37] which can be 1 month or longer (longer holding period portfolios typically have diminishing returns before trading costs as the momentum effect fades with time). Multi-month-holding portfolios can be constructed by overlapping 1-month-holding portfolios (see, e.g., [Jegadeesh and Titman, 1993]).

The above prescription does not fix the relative weights w_i of the stocks in the portfolio. For a long-only portfolio we have $w_i \geq 0$ and

$$\sum_{i=1}^{N} w_i = 1 \tag{271}$$

So, if the total investment level is I, then the stock labeled by i has $I \times w_i$ dollars invested in it. This, up to rounding, translates into $Q_i = I \times w_i / P_i(0)$ shares.[38] One can simply take uniform weights, $w_i = 1/N$ for all stocks, albeit other weighting schemes are possible. E.g., we can have nonuniform $w_i \propto 1/\sigma_i$, or $w_i \propto 1/\sigma_i^2$, etc.

For a dollar-neutral portfolio we can have negative w_i and

$$\sum_{i=1}^{N} |w_i| = 1 \tag{272}$$

$$\sum_{i=1}^{N} w_i = 0 \tag{273}$$

So, if the total investment level is $I = I_L + I_S$, where I_L is the total long investment, and I_S is the absolute value of the total short investment,[39] then the stock labeled by i has $I \times w_i$ dollars invested in it, where $w_i > 0$ for long stocks, and $w_i < 0$ for short stocks. One can simply take modulus-uniform weights, where $w_i = 1/2N_L$ for all N_L long stocks, and $w_i = -1/2N_S$ for all N_S short stocks. However, other weighting schemes are possible, e.g., as above, weights suppressed by σ_i, σ_i^2, etc.[40]

3.2 Strategy: Earnings-momentum

This strategy amounts to buying winners and selling losers as in the price-momentum strategy, but the selection criterion is based on earnings. One way to define such a

[37] Albeit, e.g., a long-only portfolio may have to be liquidated before the end of this holding period due to unforeseen events, such as market crashes.

[38] That is, assuming the stock is bought at the price $P_i(0)$, which does not account for slippage.

[39] For dollar-neutral portfolios $I_L = I_S$ and $I = 2 \times I_L$.

[40] For some additional literature on momentum strategies, see, e.g., [Antonacci, 2017], [Asem and Tian, 2010], [Barroso and Santa-Clara, 2014], [Bhojraj and Swaminathan, 2006], [Chordia and Shivakumar, 2002], [Chuang and Ho, 2014], [Cooper, Gutierrez and Hameed, 2004], [Daniel and Moskowitz, 2016], [Géczy and Samonov, 2016], [Griffin, Ji and Martin, 2003], [Grundy and Martin, 2001], [Hwang and George, 2004], [Jegadeesh and Titman, 2001], [Karolyi and Kho, 2004], [Korajczyk and Sadka, 2004], [Liu and Zhang, 2008], [Moskowitz and Grinblatt, 1999], [Rouwenhorst, 1998], [Sadka, 2002], [Siganos and Chelley-Steeley, 2006], [Stivers and Sun, 2010].

selection criterion is via standardized unexpected earnings (SUE) [Chan, Jegadeesh and Lakonishok, 1996]:[41]

$$\mathrm{SUE}_i = \frac{E_i - E'_i}{\sigma_i} \tag{274}$$

Here: E_i is the most recently announced quarterly earnings per share of the stock labeled by i; E'_i is the earnings per share announced 4 quarters ago; σ_i is the standard deviation of the unexpected earnings $E_i - E'_i$ over the last 8 quarters. Similarly to the price-momentum strategy, the trader can, e.g., construct a dollar-neutral portfolio by buying stocks in the top decile by SUE, and shorting stocks in the bottom decile.[42]

3.3 Strategy: Value

This strategy amounts to buying winners and selling losers as in the price-momentum and earnings-momentum strategies, but the selection criterion is based on value. Value can be defined as the Book-to-Price (B/P) ratio (see, e.g., [Rosenberg, Reid and Lanstein, 1985]). Here "Book" is the company's book value *per share outstanding* (so the B/P ratio is the same as the Book-to-Market ratio, where now "Book" stands for its total book value, *not* per share outstanding, and "Market" is its market capitalization). The trader can, e.g., construct a zero-cost portfolio by buying stocks in the top decile by the B/P ratio, and shorting stocks in the bottom decile. There can be variations in the definition of the B/P ratio. Thus, e.g., [Asness, Moskowitz and Pedersen, 2013] uses current (i.e., most up-to-date) prices, while [Fama and French, 1992] and some others use prices contemporaneous with the book value.[43]

3.4 Strategy: Low-volatility anomaly

This strategy is based on the empirical observation that future returns of previously low-return-volatility portfolios outperform those of previously high-return-volatility portfolios,[44] which goes counter to the "naïve" expectation that higher risk assets

[41] Also see, e.g., [Bartov, Radhakrishnan and Krinsky, 2005], [Battalio and Mendenhall, 2007], [Bernard and Thomas, 1989], [Bernard and Thomas, 1990], [Bhushan, 1994], [Chordia *et al*, 2009], [Chordia and Shivakumar, 2006], [Czaja, Kaufmann and Scholz, 2013], [Doyle, Lundholm and Soliman, 2006], [Foster, Olsen and Shevlin, 1984], [Hew *et al*, 1996], [Hirshleifer, Lim and Teoh, 2009], [Jansen and Nikiforov, 2016], [Livnat and Mendenhall, 2006], [Loh and Warachka, 2012], [Mendenhall, 2004], [Ng, Rusticus and Verdi, 2008], [Rendleman, Jones and Latané, 1982], [Stickel, 1991], [Watts, 1978].

[42] Typically, the holding period is 6 months, with diminishing returns for longer holding periods.

[43] The holding period typically is 1-6 months. For some additional literature on value strategies, see, e.g., [Erb and Harvey, 2006], [Fama and French, 1993], [Fama and French, 1996], [Fama and French, 1998], [Fama and French, 2012], [Fisher, Shah and Titman, 2016], [Gerakos and Linnainmaa, 2012], [Novy-Marx, 2013], [Piotroski, 2000], [Piotroski and So, 2012], [Stattman, 1980], [Suhonen, Lennkh and Perez, 2017], [Zhang, 2005].

[44] See, e.g., [Ang *et al*, 2006], [Ang *et al*, 2009], [Baker, Bradley and Wurgler, 2011], [Black, 1972], [Blitz and van Vliet, 2007], [Clarke, de Silva and Thorley, 2006], [Clarke, de Silva and

should yield proportionately higher returns. Thus, if σ_i is defined as the historical volatility (computed over a time series of historical returns, as in Eq. (270)), the trader can, e.g., construct a dollar-neutral portfolio by buying stocks in the bottom decile by σ_i (low-volatility stocks), and shorting stocks in the top decile (high-volatility stocks). The length of the sample used for computing the historical volatility can, e.g., be 6 months (126 trading days) to a year (252 trading days), with a similar duration for the holding period (with no "skip period" required).

3.5 Strategy: Implied volatility

This strategy is based on the empirical observation that stocks with larger increases in call implied volatilities over the previous month on average have higher future returns, while stocks with larger increases in put implied volatilities over the previous month on average have lower future returns (see, e.g., [An *et al*, 2014], [Chen, Chung and Tsai, 2016]).[45] Therefore, the trader can, e.g., construct a dollar-neutral portfolio by buying stocks in the top decile by the increase in call implied volatilities, and shorting stocks in the top decile by the increase in put implied volatilities. One can also consider variations, e.g., buying stocks in the top decile by the *difference* twixt the change in call implied volatilities and the change in put implied volatilities.

3.6 Strategy: Multifactor portfolio

This strategy amounts to buying and shorting stocks based on multiple factors such as value, momentum, etc. For instance, usually value and momentum are negatively correlated and combining them can add value (see, e.g., [Asness, Moskowitz and Pedersen, 2013]). There is a variety of ways in which $F > 1$ factors can be combined.[46] The simplest way is to diversify the exposure to the F factors with some weights w_A, where $A = 1, \ldots, F$ labels the factors. That is, if I is the total investment level, then the F portfolios (each built as above based on the corresponding factor) are allocated the investment levels $I_A = w_A \times I$, where (assuming all $w_A > 0$)

$$\sum_{A=1}^{F} w_A = 1 \qquad (275)$$

Thus, one can simply take uniform weights $w_A = 1/F$, albeit this may not be the most optimal weighting scheme. E.g., similarly to Subsection 3.1, there are weighting

Thorley, 2010], [Frazzini and Pedersen, 2014], [Fu, 2009], [Garcia-Feijóo *et al*, 2015], [Li, Sullivan and Garcia-Feijóo, 2014], [Li, Sullivan and Garcia-Feijóo, 2016], [Merton, 1987].

[45] Also see, e.g., [Bali and Hovakimian, 2009], [Bollen and Whaley, 2004], [Busch, Christensen and Nielsen, 2011], [Chakravarty, Gulen and Mayhew, 2004], [Conrad, Dittmar and Ghysels, 2013], [Cremers and Weinbaum, 2010], [Pan and Poteshman, 2006], [Xing, Zhang and Zhao, 2010].

[46] And the holding period depends on which factors are combined.

schemes with $w_A \propto 1/\sigma_A$, $w_A \propto 1/\sigma_A^2$, etc., where σ_A is the historical volatility for the corresponding factor portfolio (uniformly normalized, e.g., per dollar invested).[47]

Alternatively, consider F rankings of stocks based on the F factors. One can now combine these rankings in various ways to blend the factors. E.g., in the case of two factors, momentum and value, one can take the top (winners) and bottom (losers) quintiles by momentum and further split them into top half and bottom half, respectively, by value. Or one can take the top and bottom quintiles by value and split them by momentum.[48] Yet another way is to define demeaned ranks

$$s_{Ai} = \text{rank}(f_{Ai}) - \frac{1}{N} \sum_{j=1}^{N} \text{rank}(f_{Aj}) \tag{276}$$

where f_{Ai} is the numeric value of the factor labeled by A (e.g., momentum) for the stock labeled by i ($i = 1, \dots, N$). One can then simply average the ranks:

$$s_i = \frac{1}{F} \sum_{A=1}^{F} s_{Ai} \tag{277}$$

The combined "score" s_i can have ties, which, if need be (e.g., if there is an ambiguity at the border of the top decile) can be resolved, e.g., simply by giving preference to one of the factor rankings. Averaging over s_{Ai} simply minimizes the sum of squares of the Euclidean distances between the N-vector s_i and the K N-vectors s_{Ai}. One can introduce nonuniform weights into this sum (which would amount to a weighted average in Eq. (277)), or even use a different definition of the distance (e.g., the Manhattan distance), which would complicate the problem computationally. Etc.[49]

3.7 Strategy: Residual momentum

This is the same as the price-momentum strategy with the stock returns $R_i(t)$ replaced by the residuals $\epsilon_i(t)$ of a *serial* regression of the stock returns $R_i(t)$ over, e.g., the 3 Fama-French factors MKT(t), SMB(t), HML(t),[50] with the intercept (see,

[47] Another approach is to fix the weights w_A by optimizing a portfolio of the F expected returns corresponding to the F factors (using an invertible $F \times F$ covariance matrix for these returns).

[48] These two ways generally do not produce the same resultant portfolios.

[49] For additional literature on multifactor strategies, see, e.g., [Amenc *et al*, 2016], [Amenc *et al*, 2015], [Arnott *et al*, 2013], [Asness, 1997], [Barber, Bennett and Gvozdeva, 2015], [Cochrane, 1999], [Fama, 1996], [Grinold and Kahn, 2000], [Hsu, Lin and Vincent, 2018], [Kahn and Lemmon, 2015], [Kahn and Lemmon, 2016], [Kozlov and Petajisto, 2013], [Malkiel, 2014], [Wang, 2005].

[50] The stock returns R_i are defined in excess of the risk-free rate (the one-month Treasury bill rate); MKT is the excess return of the market portfolio; SMB is the excess return of the Small minus Big (by market capitalization) portfolio; HML is the excess return of the High minus Low (by book-to-market) portfolio. See, e.g., [Carhart, 1997], [Fama and French, 1993] for details.

e.g., [Blitz, Huij and Martens, 2011]):[51]

$$R_i(t) = \alpha_i + \beta_{1,i}\ \mathrm{MKT}(t) + \beta_{2,i}\ \mathrm{SMB}(t) + \beta_{3,i}\ \mathrm{HML}(t) + \epsilon_i(t) \tag{278}$$

The regression is run over a 36-month period [Blitz, Huij and Martens, 2011] (with the 1-month skip period) to estimate the regression coefficients α_i, $\beta_{1,i}$, $\beta_{2,i}$, $\beta_{3,i}$. Once the coefficients are estimated, the residuals can be computed for the 12-month formation period (again, with the 1-month skip period):

$$\epsilon_i(t) = R_i(t) - \beta_{1,i}\ \mathrm{MKT}(t) - \beta_{2,i}\ \mathrm{SMB}(t) - \beta_{3,i}\ \mathrm{HML}(t) \tag{279}$$

Note that α_i is not included in this computation of the residuals for the 12-month formation period as α_i was computed for the 36-month period. These residuals $\epsilon_i(t)$ are then used to compute, e.g., the risk-adjusted residual returns $\widetilde{R}_i^{risk.adj}$ (here $S = 1$ and $T = 12$; the holding period typically is 1 month, but can be longer):

$$\epsilon_i^{mean} = \frac{1}{T} \sum_{t=S}^{S+T-1} \epsilon_i(t) \tag{280}$$

$$\widetilde{R}_i^{risk.adj} = \frac{\epsilon_i^{mean}}{\widetilde{\sigma}_i} \tag{281}$$

$$\widetilde{\sigma}_i^2 = \frac{1}{T-1} \sum_{t=S}^{S+T-1} \left(\epsilon_i(t) - \epsilon_i^{mean}\right)^2 \tag{282}$$

E.g., a dollar-neutral portfolio can be constructed by buying stocks in the top decile by $\widetilde{R}_i^{risk.adj}$, and shorting stocks in the bottom decile (with (non)uniform weights).

3.8 Strategy: Pairs trading

This dollar-neutral strategy amounts to identifying a pair of historically highly correlated stocks (call them stock A and stock B) and, when a mispricing (i.e., a deviation from the high historical correlation) occurs, shorting the "rich" stock and buying the "cheap" stock. This is an example of a mean-reversion strategy. Let $P_A(t_1)$ and $P_B(t_1)$ be the prices of stock A and stock B at time t_1, and let $P_A(t_2)$ and $P_B(t_2)$ be the prices of stock A and stock B at a *later* time t_2. All prices are fully adjusted for any splits and dividends. The corresponding returns (from t_1 to t_2) are

$$R_A = \frac{P_A(t_2)}{P_A(t_1)} - 1 \tag{283}$$

$$R_B = \frac{P_B(t_2)}{P_B(t_1)} - 1 \tag{284}$$

[51] For some additional literature related to the residual momentum strategy, see, e.g., [Blitz *et al*, 2013], [Chang *et al*, 2016], [Chaves, 2012], [Chuang, 2015], [Grundy and Martin, 2001], [Gutierrez and Prinsky, 2007], [Hühn and Scholz, 2017], [Huij and Lansdorp, 2017], [Van Oord, 2016].

Since typically these returns are small, we can use an alternative definition:

$$R_A = \ln\left(\frac{P_A(t_2)}{P_A(t_1)}\right) \tag{285}$$

$$R_B = \ln\left(\frac{P_B(t_2)}{P_B(t_1)}\right) \tag{286}$$

Next, let $\widetilde{R}_A$ and $\widetilde{R}_B$ be the demeaned returns:

$$\overline{R} = \frac{1}{2}(R_A + R_B) \tag{287}$$

$$\widetilde{R}_A = R_A - \overline{R} \tag{288}$$

$$\widetilde{R}_B = R_B - \overline{R} \tag{289}$$

where $\overline{R}$ is the mean return. A stock is "rich" if its demeaned return is positive, and it is "cheap" if its demeaned return is negative. The numbers of shares Q_A, Q_B to short/buy are fixed by the total desired dollar investment I (Eq. (290)) and the requirement of dollar-neutrality (Eq. (291)):

$$P_A\ |Q_A| + P_B\ |Q_B| = I \tag{290}$$

$$P_A\ Q_A + P_B\ Q_B = 0 \tag{291}$$

where P_A, P_B are the stock prices at the time t_* the position is established ($t_* \geq t_2$).[52]

3.9 Strategy: Mean-reversion – single cluster

This is a generalization of the pairs trading strategy to $N > 2$ stocks that are historically highly correlated (e.g., stocks belonging to the same industry or sector). Let R_i, $i = 1, \dots, N$, be the returns for these N stocks:

$$R_i = \ln\left(\frac{P_i(t_2)}{P_i(t_1)}\right) \tag{292}$$

$$\overline{R} = \frac{1}{N}\sum_{i=1}^{N} R_i \tag{293}$$

$$\widetilde{R}_i = R_i - \overline{R} \tag{294}$$

[52] For some literature on pairs trading, see, e.g., [Bogomolov, 2013], [Bowen and Hutchinson, 2016], [Bowen, Hutchinson and O'Sullivan, 2010], [Caldeira and Moura, 2013], [Chen *et al*, 2017], [Do and Faff, 2010], [Do and Faff, 2012], [Elliott, Van Der Hoek and Malcolm, 2005], [Engle and Granger, 1987], [Gatev, Goetzmann and Rouwenhorst, 2006], [Huck, 2009], [Huck, 2015], [Huck and Afawubo, 2014], [Jacobs and Weber, 2015], [Kakushadze, 2015b], [Kim, 2011], [Kishore, 2012], [Krauss, 2017], [Krauss and Stübinger, 2017], [Liew and Wu, 2013], [Lin, McCrae and Gulati, 2006], [Liu, Chang and Geman, 2017], [Miao, 2014], [Perlin, 2009], [Pizzutilo, 2013], [Rad, Low and Faff, 2016], [Stübinger and Bredthauer, 2017], [Stübinger and Endres, 2017], [Vaitonis and Masteika, 2016], [Vidyamurthy, 2004], [Xie *et al*, 2014], [Yoshikawa, 2017], [Zeng and Lee, 2014].

Following the pairs trading intuition, we can short stocks with positive $\widetilde{R}_i$ and buy stocks with negative $\widetilde{R}_i$. We have the following conditions:

$$\sum_{i=1}^{N} P_i \; |Q_i| = I \tag{295}$$

$$\sum_{i=1}^{N} P_i \; Q_i = 0 \tag{296}$$

Here: I is the total desired dollar investment; Eq. (296) is the dollar-neutrality constraint; $Q_i < 0$ for short-sales; $Q_i > 0$ for buys; P_i are the prices at the time the position is established. We have 2 equations and $N > 2$ unknowns. A simple prescription (which is one out of myriad possibilities) for specifying Q_i is to have the dollar positions $D_i = P_i \; Q_i$ proportional to the demeaned returns:

$$D_i = -\gamma \; \widetilde{R}_i \tag{297}$$

where $\gamma > 0$ (recall that we short $\widetilde{R}_i > 0$ stocks and buy $\widetilde{R}_i < 0$ stocks). Then Eq. (296) is automatically satisfied, while Eq. (295) fixes γ:

$$\gamma = \frac{I}{\sum_{i=1}^{N} \left|\widetilde{R}_i\right|} \tag{298}$$

3.9.1 Strategy: Mean-reversion – multiple clusters

The mean-reversion strategy of Subsection 3.9 can be readily generalized to the case where we have $K > 1$ clusters such that stocks within each cluster are historically highly correlated.[53] We can simply treat clusters independently from each other and construct a mean-reversion strategy following the above procedure in each cluster. Then, e.g., we can allocate investments to these K independent strategies uniformly.

There is a neat way of treating all clusters in a "unified" fashion using a linear regression. Let the K clusters be labeled by $A = 1, \dots, K$. Let Λ_{iA} be an $N \times K$ matrix such that if the stock labeled by i ($i = 1, \dots, N$) belongs to the cluster labeled by A, then $\Lambda_{iA} = 1$; otherwise, $\Lambda_{iA} = 0$. We will assume that each and every stock belongs to one and only one cluster (so there are no empty clusters):

$$N_A = \sum_{i=1}^{N} \Lambda_{iA} > 0 \tag{299}$$

$$N = \sum_{A=1}^{K} N_A \tag{300}$$

[53] E.g., these clusters can correspond to sectors, such as energy, technology, healthcare, etc.

We have

$$\Lambda_{iA} = \delta_{G(i),A} \tag{301}$$
$$G : \{1, \dots, N\} \mapsto \{1, \dots, K\} \tag{302}$$

Here: G is the map between stocks and clusters; and Λ_{iA} is the loadings matrix.

Now consider a linear regression of the stock returns R_i over Λ_{iA} (without the intercept and with unit weights):

$$R_i = \sum_{A=1}^{K} \Lambda_{iA}\ f_A + \varepsilon_i \tag{303}$$

where f_A are the regression coefficients given by (in matrix notation, where R is the N-vector R_i, f is the K-vector f_A, and Λ is the $N \times K$ matrix Λ_{iA})

$$f = Q^{-1}\ \Lambda^T\ R \tag{304}$$
$$Q = \Lambda^T\ \Lambda \tag{305}$$

and ε_i are the regression residuals. For binary Λ_{iA} given by Eq. (301), these residuals are nothing but the returns R_i demeaned w.r.t. to the corresponding cluster:

$$\varepsilon = R - \Lambda\ Q^{-1}\ \Lambda^T\ R \tag{306}$$
$$Q_{AB} = N_A\ \delta_{AB} \tag{307}$$
$$\overline{R}_A = \frac{1}{N_A} \sum_{j \in J_A} R_j \tag{308}$$
$$\varepsilon_i = R_i - \overline{R}_{G(i)} = \widetilde{R}_i \tag{309}$$

where $\overline{R}_A$ is the mean return for the cluster labeled by A, and $\widetilde{R}_i$ is the demeaned return obtained by subtracting from R_i the mean return for the cluster labeled by $A = G(i)$ to which the stock labeled by i belongs: $J_A = \{i | G(i) = A\} \subset \{1, \dots, N\}$.

The demeaned returns are cluster-neutral, i.e.,

$$\sum_{i=1}^{N} \widetilde{R}_i\ \Lambda_{iA} = 0, \quad A = 1, \dots, K \tag{310}$$

Also, note that we automatically have (so D_i given by Eq. (297) satisfy Eq. (296))

$$\sum_{i=1}^{N} \widetilde{R}_i\ \nu_i = 0 \tag{311}$$

where $\nu_i \equiv 1$, $i = 1, \dots, N$, i.e., the N-vector ν is the unit vector. In the regression language, ν is the intercept. We did not have to add the intercept to the loadings matrix Λ as it is already subsumed in it:

$$\sum_{A=1}^{K} \Lambda_{iA} = \nu_i \tag{312}$$

3.10 Mean-reversion – weighted regression

The conditions (310) satisfied by the demeaned returns when the loadings matrix is binary simply mean that these returns are cluster-neutral, i.e., orthogonal to the K N-vectors $v^{(A)}$ comprising the columns of Λ_{iA}. Such orthogonality can be defined for any loadings matrix, not just a binary one. So, we can consider a generalization where the loadings matrix, call it Ω_{iA}, may have some binary columns, but generally it need not. The binary columns, if any, can, e.g., be industry (or sector) based risk factors; the non-binary columns are interpreted as some non-industry based risk factors; and the orthogonality condition

$$\sum_{i=1}^{N} \widetilde{R}_i \; \Omega_{iA}, \quad A = 1, \dots, K \tag{313}$$

can be satisfied if the twiddled returns $\widetilde{R}_i$ are related to the residuals ε_i of the regression of R_i over Ω_{iA} with some (generally nonuniform) regression weights z_i via

$$\widetilde{R} = Z \; \varepsilon \tag{314}$$

$$\varepsilon = R - \Omega \; Q^{-1} \; \Omega^T \; Z \; R \tag{315}$$

$$Z = \mathrm{diag}(z_i) \tag{316}$$

$$Q = \Omega^T \; Z \; \Omega \tag{317}$$

If the intercept is included in Ω_{iA} (i.e., a linear combination of the columns of Ω_{iA} equals the unit N-vector ν), then we automatically have

$$\sum_{i=1}^{N} \widetilde{R}_i = 0 \tag{318}$$

The weights z_i can, e.g., be taken as $z_i = 1/\sigma_i^2$, where σ_i are historical volatilities.[54]

3.11 Strategy: Single moving average

This strategy is based on the stock price crossing a moving average. One can use different types of moving averages (MAs), such as a simple moving average (SMA),

[54] For some literature on mean-reversion (a.k.a. contrarian) strategies, see, e.g., [Avellaneda and Lee, 2010], [Black and Litterman, 1991], [Black and Litterman, 1992], [Cheung, 2010], [Chin, Prevost and Gottesman, 2002], [Conrad and Kaul, 1998], [Daniel, 2001], [Da Silva, Lee and Pornrojnangkool, 2009], [Doan, Alexeev and Brooks, 2014], [Drobetz, 2001], [Hodges and Carverhill, 1993], [Idzorek, 2007], [Jansen and Nikiforov, 2016], [Jegadeesh and Titman, 1995], [Kakushadze, 2015b], [Kang, Liu and Ni, 2002], [Kudryavtsev, 2012], [Lakonishok, Shleifer and Vishny, 1994], [Lehmann, 1990], [Li *et al*, 2012], [Liew and Roberts, 2013], [Lo and MacKinlay, 1990], [Mun, Vasconcellos and Kish, 2000], [O'Tool, 2013], [Pole, 2007], [Poterba and Summers, 1988], [Satchell and Scowcroft, 2000], [Schiereck, Bondt and Weber, 1999], [Shi, Jiang and Zhou, 2015], [Yao, 2012].

or an exponential moving average (EMA):[55]

$$\mathrm{SMA}(T) = \frac{1}{T}\sum_{t=1}^{T} P(t) \tag{319}$$

$$\mathrm{EMA}(T,\lambda) = \frac{\sum_{t=1}^{T} \lambda^{t-1}\ P(t)}{\sum_{t=1}^{T} \lambda^{t-1}} = \frac{1-\lambda}{1-\lambda^T}\ \sum_{t=1}^{T} \lambda^{t-1}\ P(t) \tag{320}$$

Here: $t = 1$ corresponds to the most recent time in the time series of historical stock prices $P(t)$; T is the length of the MA (t and T are usually measured in trading days); and $\lambda < 1$ is the factor which suppresses past contributions. Below MA will refer to SMA or EMA. A simple strategy is defined as follows (P is the price at $t = 0$, on the trading day immediately following the most recent trading day $t = 1$ in the time series $P(t)$):

$$\text{Signal} = \begin{cases} \text{Establish long/liquidate short position if } P > \mathrm{MA}(T) \\ \text{Establish short/liquidate long position if } P < \mathrm{MA}(T) \end{cases} \tag{321}$$

This strategy can be run as, e.g., long-only, short-only, or both long and short. It can be straightforwardly applied to multiple stocks (on a single-stock basis, with no cross-sectional interaction between the signals for individual stocks). With a large number of stocks, it may be possible to construct (near-)dollar-neutral portfolios.

3.12 Strategy: Two moving averages

The simplest variant of this strategy replaces the stock price P in Eq. (321) by another moving average. That is, we have 2 moving averages with lengths T' and T, where $T' < T$ (e.g., $T' = 10$ and $T = 30$), and the signal is given by:

$$\text{Signal} = \begin{cases} \text{Establish long/liquidate short position if } \mathrm{MA}(T') > \mathrm{MA}(T) \\ \text{Establish short/liquidate long position if } \mathrm{MA}(T') < \mathrm{MA}(T) \end{cases} \tag{322}$$

This signal can be augmented with additional "stop-loss" rules to protect realized profits. E.g., if a long position has been established, the trader can define a threshold

[55] For $T \gg 1$ we have $\lambda^T \ll 1$ and $\mathrm{EMA}(T,\lambda) \approx (1-\lambda)\ P(1) + \lambda\ \mathrm{EMA}(T-1,\lambda)$, where $\mathrm{EMA}(T-1,\lambda)$ is based on $P(2), P(3), \dots, P(T)$. Also, for some literature on moving average based strategies, see, e.g., [BenZion *et al*, 2003], [Brock, Lakonishock and LeBaron, 1992], [Dzikevičius and Šaranda, 2010], [Edwards and Magee, 1992], [Faber, 2007], [Félix and Rodríguez, 2008], [Fifield, Power and Knipe, 2008], [Fong and Yong, 2005], [Gençay, 1996], [Gençay, 1998], [Gençay and Stengos, 1998], [Glabadanidis, 2015], [Gunasekarage and Power, 2001], [Hung, 2016], [James, 1968], [Jasemi and Kimiagari, 2012], [Kilgallen, 2012], [Li *et al*, 2015], [Lo, Mamaysky and Wang, 2000], [Metghalchi, Marcucci and Chang, 2012], [Pätäri and Vilska, 2014], [Taylor and Allen, 1992], [Weller, Friesen and Dunham, 2009], [Zakamulin, 2014a], [Zakamulin, 2015].

to liquidate the long position if the stock begins to fall (even if the shorter moving average has not crossed the longer moving average yet):

$$\text{Signal} = \begin{cases} \text{Establish long position if } \text{MA}(T') > \text{MA}(T) \\ \text{Liquidate long position if } P < (1 - \Delta) \times P_1 \\ \text{Establish short position if } \text{MA}(T') < \text{MA}(T) \\ \text{Liquidate short position if } P > (1 + \Delta) \times P_1 \end{cases} \quad (323)$$

Here Δ is some predefined percentage, e.g., $\Delta = 2\%$. So, a long position is liquidated if the current price P falls over 2% below the previous day's price P_1; and a short position is liquidated if P rises over 2% above P_1. Other variations can be used.

3.13 Strategy: Three moving averages

In some cases, using 3 moving averages with lengths $T_1 < T_2 < T_3$ (e.g., $T_1 = 3$, $T_2 = 10$, $T_3 = 21$) can help filter false signals:

$$\text{Signal} = \begin{cases} \text{Establish long position if } \text{MA}(T_1) > \text{MA}(T_2) > \text{MA}(T_3) \\ \text{Liquidate long position if } \text{MA}(T_1) \leq \text{MA}(T_2) \\ \text{Establish short position if } \text{MA}(T_1) < \text{MA}(T_2) < \text{MA}(T_3) \\ \text{Liquidate short position if } \text{MA}(T_1) \geq \text{MA}(T_2) \end{cases} \quad (324)$$

3.14 Strategy: Support and resistance

This strategy uses "support" S and "resistance" R levels, which can be computed using the "pivot point" (a.k.a. the "center") C as follows:[56]

$$C = \frac{P_H + P_L + P_C}{3} \quad (325)$$

$$R = 2 \times C - P_L \quad (326)$$

$$S = 2 \times C - P_H \quad (327)$$

Here P_H, P_L and P_C are the previous day's high, low and closing prices. One way to define a trading signal is as follows (as above, P is the current price):

$$\text{Signal} = \begin{cases} \text{Establish long position if } P > C \\ \text{Liquidate long position if } P \geq R \\ \text{Establish short position if } P < C \\ \text{Liquidate short position if } P \leq S \end{cases} \quad (328)$$

[56] Other definitions of the pivot point (e.g., using the current trading day's open price) and higher/lower support/resistance levels exist. For some literature on support and resistance strategies, see, e.g., [Amiri *et al*, 2010], [Brock, Lakonishock and LeBaron, 1992], [Garzarelli *et al*, 2014], [Hardy, 1978], [Kahneman and Tversky, 1979], [Murphy, 1986], [Osler, 2000], [Osler, 2003], [Person, 2007], [Pring, 1985], [Shiu and Lu, 2011], [Thomsett, 2003], [Zapranis and Tsinaslanidis, 2012].

3.15 Strategy: Channel

This strategy amounts to buying and selling a stock when it reaches the floor and the ceiling of a channel, respectively. A channel is a range/band, bounded by a ceiling and a floor, within which the stock price fluctuates. The trader's expectation may be that if the floor or the ceiling is reached, the stock price will bounce in the opposite direction. On the other hand, if the stock price breaks through the ceiling or the floor, the trader may conclude that a new trend has emerged and follow this new trend instead. A simple and common definition of a channel is the Donchian Channel [Donchian, 1960], where the ceiling B_{up} and the floor B_{down} are defined as follows (with the same notations as above):[57]

$$B_{up} = \max(P(1), P(2), \dots, P(T)) \tag{329}$$

$$B_{down} = \min(P(1), P(2), \dots, P(T)) \tag{330}$$

A simple trading strategy then is as follows:

$$\text{Signal} = \begin{cases} \text{Establish long/liquidate short position if } P = B_{down} \\ \text{Establish short/liquidate long position if } P = B_{up} \end{cases} \tag{331}$$

The wider the channel, the higher the volatility. Usually, the channel indicator is used together with other indicators. E.g., the signal can be more robust when a price reversal (or a channel break) occurs with an increase in the traded volume.

3.16 Strategy: Event-driven – M&A

This strategy, referred to as "merger arbitrage" or "risk arbitrage", attempts to capture excess returns generated via corporate actions such as mergers and acquisitions (M&A). A merger arbitrage opportunity arises when one publicly traded company intends to acquire another publicly traded company at a price that differs from the latter's market price. In this regard, there are two main types of transactions: cash mergers and stock mergers. In the case of a cash merger, the trader establishes a long position in the target company stock. In the case of a stock merger, the trader establishes a long position in the target company stock (call it A) and a short position in the acquirer company stock (call it B). For instance, if the current price of A is \$67, the current price of B is \$35, and under the proposed stock merger deal each share of A is swapped for 2 shares of B, then the trader buys one share of A and shorts 2 shares of B generating an initial net credit of $\$3 = 2 \times \$35 - \$67$, which is the profit per each share of A bought if the deal goes through. The trader's risk is in that, if the deal falls through, the trader will likely lose money on this trade.[58]

[57] For some additional literature on channel trading strategies, see, e.g., [Batten and Ellis, 1996], [Birari and Rode, 2014], [Dempster and Jones, 2002], [De Zwart *et al*, 2009], [Elder, 2014], [Sullivan, Timmermann and White, 1999].

[58] For some literature on merger arbitrage, see, e.g., [Andrade, Mitchell and Stafford, 2001], [Andrieş and Vîrlan, 2017], [Baker, Pan and Wurgler, 2012], [Baker and Savaşoglu, 2002], [Bester,

3.17 Strategy: Machine learning – single-stock KNN

Some strategies rely on machine learning techniques, such as the k-nearest neighbor (KNN) algorithm (see, e.g., [Altman, 1992], [Samworth, 2012]), to predict future stock returns (the target variable) based on a set of predictor (feature) variables, which can be based on technical, fundamental and/or some other data. The strategy we describe here is a single-stock strategy, i.e., for each stock the target variable is predicted using the price and volume data only for this stock (but no cross-sectional data, i.e., no data for other stocks). The target variable $Y(t)$ is defined as the cumulative return over the next T trading days (as above, the ascending integer values of t, which is measured in trading days, correspond to going back in time):

$$Y(t) = \frac{P(t-T)}{P(t)} - 1 \tag{332}$$

The predictor variables $X_a(t)$, $a = 1, \dots, m$, are defined using prices $P(t')$ and volumes $V(t')$ at times t' before t (i.e., $t' > t$), so they are out-of-sample. Examples of such variables are moving averages of the price and volume of varying lengths:

$$X_1(t) = \frac{1}{T_1} \sum_{s=1}^{T_1} V(t+s) \tag{333}$$

$$X_2(t) = \frac{1}{T_2} \sum_{s=1}^{T_2} P(t+s) \tag{334}$$

$$X_3(t) = \frac{1}{T_3} \sum_{s=1}^{T_3} P(t+s) \tag{335}$$

$$\dots \tag{336}$$

The predictor variables are further normalized to lie between 0 and 1:

$$\widetilde{X}_a(t) = \frac{X_a(t) - X_a^-}{X_a^+ - X_a^-} \tag{337}$$

where X_a^+ and X_a^- are the maximum and minimum values of $X_a(t)$ over the training period. The final ingredient is the number k of the nearest neighbors (see below). For a given value of t we can take k nearest neighbors of the m-vector $\widetilde{X}_a(t)$ among the m-vectors $\widetilde{X}_a(t')$, $t' = t+1, t+2, \dots, t+T_*$, using the KNN algorithm (here

Martinez and Rosu, 2017], [Brown and Raymond, 1986], [Cao *et al*, 2016], [Cornelli and Li, 2002], [Dukes, Frolich and Ma, 1992], [Hall, Pinnuck and Thorne, 2013], [Harford, 2005], [Hsieh and Walkling, 2005], [Huston, 2000], [Jetley and Ji, 2010], [Karolyi and Shannon, 1999], [Khan, 2002], [Larker and Lys, 1987], [Lin, Lan and Chuang, 2013], [Maheswaran and Yeoh, 2005], [Mitchell and Pulvino, 2001], [Officer, 2004], [Officer, 2006], [Samuelson and Rosenthal, 1986], [Subramanian, 2004], [Van Tassel, 2016], [Walkling, 1985].

T_* is the sample size). For KNN we can use the Euclidean distance $D(t, t')$ between $\widetilde{X}_a(t)$ and $\widetilde{X}_a(t')$ defined as

$$[D(t, t')]^2 = \sum_{a=1}^{m} (\widetilde{X}_a(t) - \widetilde{X}_a(t'))^2 \tag{338}$$

However, we can use some other distance (e.g., the Manhattan distance). Let the k nearest neighbors of $\widetilde{X}_a(t)$ be $\widetilde{X}_a(t'_\alpha(t))$, $\alpha = 1, \dots, k$. (Note that the k values $t'_\alpha(t)$ depend on t.) Then we can *define* the *predicted* value $\mathcal{Y}(t)$ simply as an average of the corresponding realized values $Y(t'_\alpha(t))$:

$$\mathcal{Y}(t) = \frac{1}{k} \sum_{\alpha=1}^{k} Y(t'_\alpha(t)) \tag{339}$$

Alternatively, we can, e.g., consider a linear model

$$\mathcal{Y}(t) = \sum_{\alpha=1}^{k} Y(t'_\alpha(t))\ w_\alpha + v \tag{340}$$

and fix the coefficients w_α and v by running a regression[59] of the realized values $Y(t)$ over $Y(t'_\alpha(t))$ for some number – call it M – of values of t. I.e., we pull $Y(t)$ for these values of t into an M-vector and regress it over the $M \times k$ matrix of the corresponding values $Y(t'_\alpha(t))$. The coefficients of this regression are w_α and v.

The advantage of using Eq. (339) is simplicity – there are no parameters to train in this case. We still have to backtest the strategy (see below) out-of-sample. The disadvantage is that equally weighting contributions of all k nearest neighbors could be suboptimal. In this regard, there are various (e.g., distance-based) weighting schemes one may consider. Nontrivial weighting is precisely what Eq. (340) intends to capture. However, this requires training and cross-validation (using metrics such as root mean square error), and the fitted parameters w_α and v can be (and often are) out-of-sample unstable. The data can be split, e.g., 60% for training and 40% for cross-validation. Ultimately, the strategy must backtest well out-of-sample.

The signal at $t = 0$ can be defined using the predicted value $\mathcal{Y} = \mathcal{Y}(0)$, which is the expected return for the next T days. For single-stock trading[60] one can simply define thresholds for establishing long and short trades, and liquidating existing

[59] We can run this regression without the intercept, in which case we only have the coefficients w_α, or with the intercept, in which case we also have the coefficient v.

[60] Alternatively, one can use expected returns $\mathcal{Y}_i$ computed for N stocks (where $N \gg 1$) using a machine learning algorithm as above and then use these expected returns in multi-stock cross-sectional strategies such as mean-reversion/statistical arbitrage.

positions, e.g., as follows:[61]

$$\text{Signal} = \begin{cases} \text{Establish long position if } \mathcal{Y} > z_1 \\ \text{Liquidate long position if } \mathcal{Y} \leq z_2 \\ \text{Establish short position if } \mathcal{Y} < -z_1 \\ \text{Liquidate short position if } \mathcal{Y} \geq -z_2 \end{cases} \quad (341)$$

Here, z_1 and z_2 are trader-defined thresholds. This signal must be backtested out-of-sample. The number k of nearest neighbors can be optimized using a backtest (by trying a set of values of k). Alternatively, one can use a common heuristic, e.g., $k = \text{floor}(\sqrt{T_*})$ or $k = \text{ceiling}(\sqrt{T_*})$. Also see, e.g., [Hall, Park and Samworth, 2008].

3.18 Strategy: Statistical arbitrage – optimization

Let C_{ij} be the sample or model covariance matrix for the N stock returns in a portfolio.[62] Let D_i be the dollar holdings in our portfolio. The *expected* portfolio P&L P, volatility V and Sharpe ratio S are given by

$$P = \sum_{i=1}^{N} E_i \, D_i \quad (342)$$

$$V^2 = \sum_{i,j=1}^{N} C_{ij} \, D_i \, D_j \quad (343)$$

$$S = P/V \quad (344)$$

Here E_i are the expected stock returns. Instead of the dollar holdings D_i, it is more convenient to work with dimensionless holding weights (which are positive/negative for long/short positions)

$$w_i = D_i/I \quad (345)$$

[61] For some literature on using machine learning for predicting stock returns, see, e.g., [Adam and Lin, 2001], [Ang and Quek, 2006], [Chen, 2014], [Chen, Leung and Daouk, 2003], [Creamer and Freund, 2007], [Creamer and Freund, 2010], [Gestel *et al*, 2001], [Grudnitski and Osborn, 1993], [Huang, Nakamori and Wang, 2005], [Huang and Tsai, 2009], [Huerta, Elkan and Corbacho, 2013], [Kablan, 2009], [Kakushadze and Yu, 2016b], [Kakushadze and Yu, 2017c], [Kakushadze and Yu, 2018a], [Kara, Boyacioglu and Baykan, 2011], [Kim, 2003], [Kim, 2006], [Kim and Han, 2000], [Kordos and Cwiok, 2011], [Kryzanowski, Galler and Wright, 1993], [Kumar and Thenmozhi, 2001], [Liew and Mayster, 2018], [Lu, Lee and Chiu, 2009], [Milosevic, 2016], [Novak and Velušçek, 2016], [Ou and Wang, 2009], [Refenes, Zapranis and Francis, 1994], [Rodríguez-González *et al*, 2011], [Saad, Prokhorov and Wunsch, 1998], [Schumaker and Chen, 2010], [Subha and Nambi, 2012], [Tay and Cao, 2001], [Teixeira and de Oliveira, 2010], [Tsai and Hsiao, 2010], [Vanstone and Finnie, 2009], [Yao and Tan, 2000], [Yao, Tan and Poh, 1999], [Yu, Wang and Lai, 2005].

[62] The sample covariance matrix based on a time series of historical returns is singular if $T \leq N + 1$, where T is the number of observations in the time series. Even if it is nonsingular, unless $T \gg N$, which is rarely (if ever) the case, the off-diagonal elements of the sample covariance matrix typically are unstable out-of-sample. Therefore, in practice, typically a model covariance matrix (which is positive-definite and should be sufficiently stable out-of-sample) is used (see below).

where I is the total investment level. The holding weights satisfy the condition

$$\sum_{i=1}^{N} |w_i| = 1 \tag{346}$$

We have $P = I \times \widetilde{P}$, $V = I \times \widetilde{V}$ and $S = \widetilde{P}/\widetilde{V}$, where

$$\widetilde{P} = \sum_{i=1}^{N} E_i \ w_i \tag{347}$$

$$\widetilde{V}^2 = \sum_{i,j=1}^{N} C_{ij} \ w_i \ w_j \tag{348}$$

To determine the portfolio weights w_i, often one requires that the Sharpe ratio [Sharpe, 1966], [Sharpe, 1994] be maximized:

$$S \rightarrow \max \tag{349}$$

Assuming no additional conditions on w_i (e.g., upper or lower bounds), the solution to Eq. (349) in the absence of trading costs is given by

$$w_i = \gamma \ \sum_{j=1}^{N} C_{ij}^{-1} E_j \tag{350}$$

where C^{-1} is the inverse of C, and the normalization coefficient γ is determined from Eq. (346) (and $\gamma > 0$ so $\widetilde{P} > 0$). The weights given by Eq. (350) generically do not correspond to a dollar-neutral portfolio. To have a dollar-neutral portfolio, we need to maximize the Sharpe ratio subject to the dollar-neutrality constraint.

3.18.1 Dollar-neutrality

We can achieve dollar-neutrality as follows. In the absence of bounds, trading costs, etc., the Sharpe ratio is invariant under simultaneous rescalings of all holding weights $w_i \rightarrow \zeta \ w_i$, where $\zeta > 0$. Due to this scale invariance, the Sharpe ratio maximization problem can be recast in terms of minimizing a quadratic objective function:

$$g(w, \lambda) = \frac{\lambda}{2} \sum_{i,j=1}^{N} C_{ij} \ w_i \ w_j - \sum_{i=1}^{N} E_i \ w_i \tag{351}$$

$$g(w, \lambda) \rightarrow \min \tag{352}$$

where $\lambda > 0$ is a parameter, and minimization is w.r.t. w_i. The solution is given by

$$w_i = \frac{1}{\lambda} \ \sum_{j=1}^{N} C_{ij}^{-1} E_j \tag{353}$$

and λ is fixed via Eq. (346). The objective function approach – which is the mean-variance optimization [Markowitz, 1952] – is convenient if we wish to impose *linear homogeneous* constraints (which do not spoil the aforesaid scale invariance) on w_i, e.g., the dollar-neutrality constraint. We introduce a Lagrange multiplier μ:[63]

$$g(w, \mu, \lambda) = \frac{\lambda}{2} \sum_{i,j=1}^{N} C_{ij}\ w_i\ w_j - \sum_{i=1}^{N} E_i\ w_i - \mu\ \sum_{i=1}^{N} w_i \tag{354}$$

$$g(w, \mu, \lambda) \rightarrow \min \tag{355}$$

Minimization w.r.t. w_i and μ now gives the following equations:

$$\lambda\ \sum_{j=1}^{N} C_{ij}\ w_j = E_i + \mu \tag{356}$$

$$\sum_{i=1}^{N} w_i = 0 \tag{357}$$

So we have dollar-neutrality. The solution to Eqs. (356) and (357) is given by:

$$w_i = \frac{1}{\lambda} \left[\sum_{j=1}^{N} C^{-1}_{ij} E_j - \sum_{j=1}^{N} C^{-1}_{ij}\ \frac{\sum_{k,l=1}^{N} C^{-1}_{kl} E_l}{\sum_{k,l=1}^{N} C^{-1}_{kl}} \right] \tag{358}$$

By construction, w_i satisfy the dollar-neutrality constraint (357), and λ is fixed via Eq. (346). The expected returns E_i can be based on mean-reversion, momentum, machine learning or other signals. Eq. (358) constructs a dollar-neutral portfolio with "risk management" built in. E.g., the weights w_i (roughly) are suppressed by stock volatilities σ_i (where $\sigma_i^2 = C_{ii}$) assuming that on average $|E_i|$ are of order σ_i.[64]

The above implementation of the dollar-neutrality constraint via minimizing the quadratic objective function (354) is equivalent to imposing this constraint in Sharpe ratio maximization as no trading costs, position/trading bounds, non-linear/inhomogeneous constraints, etc., are present. More generally Sharpe ratio maximization is not equivalent to minimizing a quadratic objective function (see, e.g., [Kakushadze, 2015b]), albeit in practice usually the latter approach is used.

[63] By introducing multiple Lagrange multipliers, we can have multiple linear homogeneous constraints (see, e.g., [Kakushadze, 2015b]).

[64] Typically, C_{ij} is a multifactor risk model covariance matrix. For a general discussion, see, e.g., [Grinold and Kahn, 2000]. For explicit implementations (including source code), see, e.g., [Kakushadze, 2015e], [Kakushadze and Yu, 2016a], [Kakushadze and Yu, 2017a]. For multifactor models, the weights are *approximately* neutral w.r.t. the columns of the factor loadings matrix. The exact neutrality is attained in the zero specific risk limit, where optimization reduces to a weighted regression (see, e.g., [Kakushadze, 2015b]).

3.19 Strategy: Market-making

Over-simplistically, this strategy amounts to capturing the bid-ask spread for a given stock and can be (again, over-simplistically) summarized as follows:

$$\text{Rule} = \begin{cases} \text{Buy at the bid} \\ \text{Sell at the ask} \end{cases} \tag{359}$$

In a market where most order flow is "dumb" (or uninformed), this strategy on average would work very well. However, in a market where most order flow is "smart" (or informed, i.e., "toxic"), this strategy, as stated, would lose money. This is because of *adverse selection*, where, precisely because most order flow is smart, most fills at the bid (ask) would be when the market is trading through it downward (upward), so these trades would lose money. Furthermore, most limit orders to buy (sell) at the bid (ask) would never be filled as the price would run away from them, i.e., increase (decrease). So, ideally, this strategy should be structured such that it captures dumb order flow and avoids smart order flow, which is not that simple.

One approach is, at any given time, within a short time horizon, to stay on the "right" side of the market, i.e., to have a short-horizon signal indicating the direction of the market and place limit orders accordingly (to buy at the bid if the signal indicates a price increase, and to sell at the ask if the signal indicates a price decrease). If the signal were (magically) 100% correct, this would capture the dumb order flow assuming that the orders get filled. This is a big assumption as for this to be guaranteed, the trader would have to be #1 in the queue among many other market participants placing limit orders at the same price point. This is where high frequency trading comes in – it is essentially all about speed with which orders are placed, canceled, and cancel-replaced. Infrastructure and technology are key in this.

Another possibility is to modulate the short-horizon signal with a longer-horizon signal (which can still be an intraday signal). The longer-horizon signal typically will have a higher cents-per-share[65] than the shorter-horizon signal. Now certain trades can be profitable even with adverse selection, because they are established based on the longer-horizon signal. I.e., they "lose money" in the short term due to adverse selection (as the market trades through the corresponding limit orders), but they make money in a longer term. The market-making aspect of this is valuable as placing a passive limit order as opposed to an aggressive market or limit order saves money. On the other hand, in some cases, if the longer-horizon signal is strong enough and the shorter-horizon signal is in the same direction, a passive limit order would likely not get filled and it may make more sense to place an aggressive order. Such aggressive order flow is not dumb but smart, as it is based on nontrivial short- and long-horizon signals with a positive expected return.[66] And speed still matters.

[65] "Cents-per-share" is defined as the realized P&L in cents (as opposed to dollars) divided by the total shares traded (which includes both establishing and liquidating trades). Note that the longer-horizon signal generally has a lower Sharpe ratio than the shorter-horizon signal.

[66] Dumb order flow can come from, e.g., uninformed retail traders. It can also come from ultra-

3.20 Strategy: Alpha combos

With technological advances – hardware becoming cheaper and more powerful – it is now possible to data mine hundreds of thousands and even millions of alphas using machine learning methods. Here the term "alpha" – following common trader lingo – generally means any reasonable "expected return" that one may wish to trade on and is not necessarily the same as the "academic" alpha.[67] In practice, often the detailed information about how alphas are constructed may not even be available, e.g., the only data available could be the position data, so "alpha" then is a set of instructions to achieve certain stock (or some other instrument) holdings by some times $t_1, t_2, \dots$ Also, "machine learning" here refers to sophisticated methods that go beyond single-stock methods such as those discussed in Subsection 3.17 and involve cross-sectional analyses based on price-volume as well as other types of data (e.g., market cap, some other fundamental data such as earnings, industry classification data, sentiment data, etc.) for a large number of stocks (typically, a few thousand and up). 101 explicit examples of such quantitative trading alphas are given in [Kakushadze, 2016].[68] The flipside is that these ubiquitous alphas are faint, ephemeral and cannot be traded on their own as any profit on paper would be eaten away by trading costs. To mitigate this, one combines a large number of such alphas and trades the so-combined "mega-alpha". Hence "alpha combo" strategies.

This is not critical, but for definiteness let us assume that all alphas trade the same underlying instruments, even more concretely, the same universe of (say, 2,500) most liquid U.S. stocks. Each alpha produces desired holdings for this trading universe. What we need is the weights with which to combine individual alphas, whose number N can be large (in hundreds of thousands or even millions).[69] Here

long-horizon institutional traders (mutual funds, pension funds, etc.), whose outlook can be months or years and who are not concerned about a few pennies' worth of difference in the execution price on short horizons (i.e., this is only "short-term dumb" order flow). For a more detailed discussion, see, e.g., [Kakushadze, 2015d], [Lo, 2008]. For some literature on high frequency trading and market-making, see, e.g., [Aldridge, 2013], [Anand and Venkataraman, 2016], [Avellaneda and Stoikov, 2008], [Baron *et al*, 2014], [Benos *et al*, 2017], [Benos and Sagade, 2016], [Biais and Foucault, 2014], [Biais, Foucault and Moinas, 2014], [Bowen, Hutchinson and O'Sullivan, 2010], [Bozdog *et al*, 2011], [Brogaard and Garriott, 2018], [Brogaard *et al*, 2015], [Brogaard, Hendershott and Riordan, 2014], [Budish, Cramton and Shim, 2015], [Carrion, 2013], [Carrion and Kolay, 2017], [Easley, López de Prado and O'Hara, 2011], [Easley, López de Prado and O'Hara, 2012], [Egginton, Van Ness and Van Ness, 2016], [Hagströmer and Nordén, 2013], [Hagströmer, Nordén and Zhang, 2014], [Harris and Namvar, 2016], [Hasbrouck and Saar, 2013], [Hendershott, Jones and Menkveld, 2011], [Hendershott, Jones and Menkveld, 2013], [Hendershott and Riordan, 2013], [Hirschey, 2018], [Holden and Jacobsen, 2014], [Jarrow and Protter, 2012], [Khandani and Lo, 2011], [Kirilenko *et al*, 2017], [Korajczyk and Murphy, 2017], [Kozhan and Tham, 2012], [Li *et al*, 2014], [Madhavan, 2012], [Menkveld, 2013], [Menkveld, 2016], [Muthuswamy *et al*, 2011], [O'Hara, 2015], [Pagnotta and Philippon, 2012], [Riordan and Storkenmaier, 2012], [Van Kervel and Menkveld, 2017].

[67] By "academic" alpha we mean Jensen's alpha [Jensen, 1968] or a similar performance index.

[68] This is a secretive field, so literature on this subject is very scarce. Also see, e.g., [Kakushadze and Tulchinsky, 2016], [Tulchinsky *et al*, 2015].

[69] Note that N here refers to the number of alphas, not the number of underlying stocks.

is a procedure for fixing the alpha weights w_i, $i = 1, \dots, N$ [Kakushadze and Yu, 2017b] (also see [Kakushadze and Yu, 2018a]):

- 1) Start with a time series of realized *alpha* returns[70] R_{is}, $i = 1, \dots, N$, $s = 1, \dots, M + 1$.
- 2) Calculate the serially demeaned returns $X_{is} = R_{is} - \frac{1}{M+1} \sum_{s=1}^{M+1} R_{is}$.
- 3) Calculate sample variances of alpha returns[71] $\sigma_i^2 = \frac{1}{M} \sum_{s=1}^{M+1} X_{is}^2$.
- 4) Calculate the normalized demeaned returns $Y_{is} = X_{is}/\sigma_i$.
- 5) Keep only the first M columns in Y_{is}: $s = 1, \dots, M$.
- 6) Cross-sectionally demean Y_{is}: $\Lambda_{is} = Y_{is} - \frac{1}{N} \sum_{j=1}^{N} Y_{js}$.
- 7) Keep only the first $M - 1$ columns in Λ_{is}: $s = 1, \dots, M - 1$.
- 8) Take the expected alpha returns E_i and normalize them: $\widetilde{E}_i = E_i/\sigma_i$. One (but by far not the only) way of computing expected alpha returns is via d-day moving averages (note that d need not be the same as T):

$$E_i = \frac{1}{d} \sum_{s=1}^{d} R_{is} \tag{360}$$

- 9) Calculate the residuals $\widetilde{\varepsilon}_i$ of the regression (without the intercept and with unit weights) of $\widetilde{E}_i$ over Λ_{is}.
- 10) Set the alpha portfolio weights to $w_i = \eta\, \widetilde{\varepsilon}_i/\sigma_i$.
- 11) Set the normalization coefficient η such that $\sum_{i=1}^{N} |w_i| = 1$.

3.21 A few comments

We end this section with a few comments on some of the stock trading strategies discussed above. First, single-stock technical analysis strategies (i.e., those based solely on single-stock as opposed to cross-sectional data) such as those based on moving averages, support and resistance, channel and even single-stock KNN, are deemed "unscientific" by many professionals and academics. On the face of it, "fundamentally" speaking (not to be confused with fundamental analysis), there is no reason why, say, a short moving average crossing a long moving average should have any forecasting power.[72] This is not to say that moving averages are "unscientific" or that they should not be used. After all, e.g., trend following/momentum strategies are based on moving averages, i.e., the expected returns are computed via moving averages. However, looking at a large cross-section of stocks brings in a *statistical* element into the game. Mean-reversion is expected to work because stocks are expected to be correlated if they belong to the same industries, etc. This relates back

[70] Here $s = 1, \dots, T = M + 1$ labels the times t_s, where, as before, t_1 corresponds to the most recent time (albeit the time direction is not crucial below), and the alpha returns are $R_{is} = R_i(t_s)$. Typically, the alpha returns are computed daily, from close to close.

[71] Their normalization is immaterial in what follows.

[72] *Arguendo*, the momentum effect may appear to provide a basis for such forecasting power in some cases. However, then one could argue, e.g., that these are momentum strategies in disguise.

to fundamental analysis and – even more importantly – to the investors' *perception* of how stock prices/returns "should" behave based on the companies' fundamentals. However, here too it is important to keep in mind that the stock market – an imperfect man-made construct – is not governed by laws of nature the same way as, say, the motion of planets in the solar system is governed by fundamental laws of gravity (see, e.g., [Kakushadze, 2015d]). The markets behave the way they do because their participants behave in certain ways, which are sometimes irrational and certainly not always efficient. In this regard, the key difference between technical analysis strategies and statistical arbitrage strategies is that the latter are based on certain perceptions trickled down from longer holding horizons (fundamental analysis based strategies) to shorter horizons (statistical arbitrage) further enhanced by statistics, i.e., the fact that these strategies are based on a large number of stocks whose properties are further "stratified" according to some statistical and other features.

This brings us to the second point relating to precisely these "stratifications" in the context of statistical arbitrage. Thus, in Subsection 3.10 we can use a binary industry classification matrix as the loadings matrix Ω_{iA}. Such industry classifications are based on pertinent fundamental/economic data, such as companies' products and services, revenue sources, suppliers, competitors, partners, etc. They are essentially independent of the pricing data and, if well-built, tend to be rather stable out-of-sample as companies seldom jump industries. However, binary classifications can also be built based purely on pricing data, via clustering algorithms (see, e.g., [Kakushadze and Yu, 2016b]). Alternatively, the matrix Ω_{iA} can be non-binary and built using, say, principal components (see, e.g., [Kakushadze and Yu, 2017a]). Some of the columns of Ω_{iA} can be based on longer-horizon style risk factors such as value, growth, size, momentum, liquidity and volatility (see, e.g., [Ang *et al*, 2006], [Anson, 2013], [Asness, 1995], [Asness *et al*, 2001], [Asness, Porter and Stevens, 2000], [Banz, 1981], [Basu, 1977], [Fama and French, 1992], [Fama and French, 1993], [Haugen, 1995], [Jegadeesh and Titman, 1993], [Lakonishok, Shleifer and Vishny, 1994], [Liew and Vassalou, 2000], [Pástor and Stambaugh, 2003], [Scholes and Williams, 1977]),[73] or shorter-horizon style factors [Kakushadze, 2015c].

4 Exchange-traded funds (ETFs)

4.1 Strategy: Sector momentum rotation

Empirical evidence suggests that the momentum effect exists not only for individual stocks but also for sectors and industries.[74] A sector momentum rotation strategy is

[73] For (il)liquidity related considerations, also see, e.g., [Amihud, 2002].

[74] For some pertinent literature, see, e.g., [Cavaglia and Vadim, 2002], [Conover *et al*, 2008], [Doeswijk and Vliet, 2011], [Dolvin and Kirby, 2011], [Gao and Ren, 2015], [Hong, Torous and Valkanov, 2007], [Levis and Liodakis, 1999], [Moskowitz and Grinblatt, 1999], [O'Neal, 2000], [Sefton and Scowcroft, 2005], [Simpson and Grossman, 2016], [Sorensen and Burke, 1986], [Stoval, 1996], [Swinkels, 2002], [Szakmary and Zhou, 2015], [Wang *et al*, 2017].

based on overweighing holdings in outperforming sectors and underweighing holdings in underperforming sectors, where the "outperformance" and "underperformance" are based on momentum during the past T-month formation period (which typically ranges from 6 to 12 months). ETFs concentrated in specific sectors/industries offer a simple way to implement sector/industry rotation without having to buy or sell a large number of underlying stocks. Similarly to Subsection 3.1, as a measure of sector/industry momentum, we can use the corresponding ETF's cumulative return:

$$R_i^{cum}(t) = \frac{P_i(t)}{P_i(t+T)} - 1 \tag{361}$$

Here $P_i(t)$ is the price of the ETF labeled by i. (As above, $t+T$ is T months in the *past* w.r.t. t.) Right after time t, the trader can, e.g., buy the ETFs in the top decile by $R_i^{cum}(t)$ and hold the portfolio for a holding period (typically 1 to 3 months). Dollar-neutral strategies can also be constructed by, e.g., buying ETFs in the top decile and shorting ETFs in the bottom decile (as stocks, ETFs can be shorted).[75]

4.1.1 Strategy: Sector momentum rotation with MA filter

This is a variation/refinement of the sector momentum rotation strategy. An ETF in the top (bottom) decile is bought (sold) only if it passes an additional filter based on a moving average $\text{MA}(T')$ of this ETF's price:

$$\text{Rule} = \begin{cases} \text{Buy top-decile ETFs only if } P > \text{MA}(T') \\ \text{Short bottom-decile ETFs only if } P < \text{MA}(T') \end{cases} \tag{362}$$

Here P is the ETF's price at the time of the transaction, and $\text{MA}(T')$ is computed using *daily* prices (T' can but need not be equal T; e.g., T' can be 100 to 200 days).

4.1.2 Strategy: Dual-momentum sector rotation

In long-only strategies, to mitigate the risk of buying ETFs when the broad market is trending down, relative (i.e., cross-sectional) momentum of sector ETFs can be augmented by the absolute (i.e., time-series) momentum of, e.g., a broad market index ETF (see, e.g., [Antonacci, 2014], [Antonacci, 2017]).[76] So, a long position based on the sector rotation signal (discussed above) is established only if the broad

[75] For some literature on ETFs, see, e.g., [Agapova, 2011a], [Aldridge, 2016], [Ben-David, Franzoni and Moussawi, 2017], [Bhattacharya *et al*, 2017], [Buetow and Henderson, 2012], [Clifford, Fulkerson and Jordan, 2014], [Hill, Nadig and Hougan, 2015], [Krause, Ehsani and Lien, 2014], [Madhavan, 2016], [Madura and Ngo, 2008], [Nyaradi, 2010], [Oztekin *et al*, 2017].

[76] For some additional literature on relative momentum, absolute momentum and related topics, see, e.g., [Ahn, Conrad and Dittmar, 2003], [Bandarchuk and Hilscher, 2013], [Berk, Green and Naik, 1999], [Cooper, Gutierrez and Hameed, 2004], [Fama and French, 2008], [Hurst, Ooi and Pedersen, 2017], [Johnson, 2002], [Liu and Zhang, 2008], [Moskowitz, Ooi and Pedersen, 2012], [Sagi and Seasholes, 2007], [Schwert, 2003], [Zhang, 2006].

market index has an upward trend; otherwise, the total available funds are invested into an ETF (e.g., gold or Treasury ETF) uncorrelated with the broad market index:

$$\text{Rule} = \begin{cases} \text{Buy top-decile ETFs if } P > \text{MA}(T') \\ \text{Buy an uncorrelated ETF if } P \leq \text{MA}(T') \end{cases} \tag{363}$$

Here P is the broad market index ETF's price at the time of the transaction, and $\text{MA}(T')$ is the moving average of this ETF's price. Typically, T' is 100 to 200 days.

4.2 Strategy: Alpha rotation

This is the same as the sector momentum rotation strategy with the cumulative ETF returns R_i^{cum} replaced by ETF alphas α_i, which are the regression coefficients corresponding to the intercept in a *serial* regression of the ETF returns[77] $R_i(t)$ over, e.g., the 3 Fama-French factors $\text{MKT}(t)$, $\text{SMB}(t)$, $\text{HML}(t)$ (see fn. 50):[78]

$$R_i(t) = \alpha_i + \beta_{1,i}\ \text{MKT}(t) + \beta_{2,i}\ \text{SMB}(t) + \beta_{3,i}\ \text{HML}(t) + \epsilon_i(t) \tag{364}$$

4.3 Strategy: R-squared

Empirical studies for mutual funds (see, e.g., [Amihud and Goyenko, 2013], [Ferson and Mo, 2016]) and ETFs (see, e.g., [Garyn-Tal, 2014a], [Garyn-Tal, 2014b]) suggest that augmenting alpha by an indicator based on R^2 of a *serial* regression of the returns $R_i(t)$ over multiple factors, e.g., the 3 Fama-French factors $\text{MKT}(t)$, $\text{SMB}(t)$, $\text{HML}(t)$ plus Carhart's momentum factor $\text{MOM}(t)$ (see fn. 50), adds value in forecasting future returns. Thus, from the serial regression

$$R_i(t) = \alpha_i + \beta_{1,i}\ \text{MKT}(t) + \beta_{2,i}\ \text{SMB}(t) + \beta_{3,i}\ \text{HML}(t) + \beta_{4,i}\ \text{MOM}(t) + \epsilon_i(t) \tag{365}$$

we can estimate α_i (the regression coefficients corresponding to the intercept) and the regression R^2, which is defined as ("SS" stands for "sum of squares"):

$$R^2 = 1 - \frac{\text{SS}_{res}}{\text{SS}_{tot}} \tag{366}$$

$$\text{SS}_{res} = \sum_{i=1}^{N} \epsilon_i^2(t) \tag{367}$$

$$\text{SS}_{tot} = \sum_{i=1}^{N} (R_i(t) - \overline{R}(t))^2 \tag{368}$$

$$\overline{R}(t) = \frac{1}{N} \sum_{i=1}^{N} R_i(t) \tag{369}$$

[77] Typically, the estimation period is 1 year, and $R_i(t)$ are daily or weekly returns.

[78] Alpha here is Jensen's alpha defined for ETF returns as opposed to mutual fund returns as in [Jensen, 1968]. For some additional literature related to Jensen's alpha, see, e.g., [Bollen and Busse, 2005], [Droms and Walker, 2001], [Elton, Gruber and Blake, 1996a], [Goetzmann and Ibbotson, 1994], [Grinblatt and Titman, 1992], [Jan and Hung, 2004].

An R-squared strategy then amounts to overweighing ETFs with higher "selectivity" (defined as $1-R^2$ [Amihud and Goyenko, 2013]) and underweighing ETFs with lower "selectivity". E.g., one can first sort ETFs into quintiles by R^2, and then sort ETFs in each such quintile into further sub-quintiles by alpha (resulting in 25 groups of ETFs). One can then, e.g., buy ETFs in the group corresponding to the lowest R^2 quintile and its highest alpha sub-quintile and sell ETFs in the group corresponding to the highest R^2 quintile and its lowest alpha sub-quintile. Other variations are possible. Finally, the estimation period and the returns for R^2 can be the same as in the alpha rotation strategy (see Subsection 4.2 and fn. 77). However, longer estimation periods can be considered, especially if $R_i(t)$ are monthly returns.[79]

4.4 Strategy: Mean-reversion

One way (among myriad others) to construct a mean-reversion strategy for ETFs is to use the Internal Bar Strength (IBS) based on the previous day's close P_C, high P_H and low P_L prices:[80]

$$\text{IBS} = \frac{P_C - P_L}{P_H - P_L} \tag{370}$$

Note that IBS ranges from 0 to 1.[81] An ETF can be thought of as being "rich" if its IBS is close to 1, and as "cheap" if its IBS is close to 0. Upon sorting a universe of ETFs cross-sectionally by IBS, a dollar-neutral strategy can, e.g., be constructed by selling ETFs in the top decile and buying ETFs in the bottom decile. As with stock strategies discussed above, weights can be uniform for all long and all short ETFs, respectively, or nonuniform, e.g., based on historical ETF volatilities. Furthermore, mean-reversion strategies we discussed above for stocks can also be adapted to ETFs.

4.5 Strategy: Leveraged ETFs (LETFs)

A leveraged (inverse) ETF seeks to double or triple (the inverse of) the daily return of its underlying index.[82] To maintain a daily leverage of 2× or 3×, LETFs rebalance

[79] Also, note that in [Amihud and Goyenko, 2013] R^2 is a measure of active management of a mutual fund. In [Garyn-Tal, 2014a], [Garyn-Tal, 2014b] R^2 is applied to actively managed ETFs. For some additional literature on actively managed ETFs, see, e.g., [Mackintosh, 2017], [Meziani, 2015], [Rompotis, 2011a], [Rompotis, 2011b], [Schizas, 2014], [Sherrill and Upton, 2018].

[80] See, e.g., [Pagonidis, 2014]. For some additional related literature, see, e.g., [Brown, Davies and Ringgenberg, 2018], [Caginalp, DeSantis and Sayrak, 2014], [Chan, 2013], [Dunis, Laws and Rudy, 2013], [Lai, Tseng and Huang, 2016], [Levy and Lieberman, 2013], [Marshall, Nguyen and Visaltanachoti], [Rudy, Dunis and Laws, 2010], [Schizas, Thomakos and Wang, 2011], [Smith and Pantilei, 2015], [Yu and Webb, 2014].

[81] An equivalent but more symmetrical measure is $Y = \text{IBS} - 1/2 = (P_C - P_*)/(P_H - P_L)$, where $P_* = (P_H + P_L)/2$. Note that Y ranges from $1/2$ for $P_C = P_H$ to $-1/2$ for $P_C = P_L$.

[82] For some literature on leveraged ETFs, see e.g., [Avellaneda and Zhang, 2010], [Bai, Bond and Hatch, 2015], [Charupat and Miu, 2011], [Cheng and Madhavan, 2010], [Ivanov and Lenkey, 2014], [Jarrow, 2010], [Jiang and Peterburgsky, 2017], [Lu, Wang and Zhang, 2012], [Shum *et al*, 2016], [Tang and Xu, 2013], [Trainor, 2010], [Tuzun, 2013].

every day, which requires buying on the days when the market is up and selling when the market is down. This can result in a negative drift in the long term, which can be exploited by shorting both a leveraged ETF and a leveraged inverse ETF (both with the same leverage and for the same underlying index) and investing the proceeds into, e.g., a Treasury ETF. This strategy can have a significant downside risk in the short term if one of the short ETF legs has a sizable positive return.

4.6 Strategy: Multi-asset trend following

One allure of ETFs is their diversification power: ETFs allow to gain exposure to different sectors, countries, asset classes, factors, etc., by taking positions in a relatively small number of ETFs (as opposed to taking positions in a large number of underlying instruments, e.g., thousands of stocks). Here we focus on long-only trend-following portfolios. One needs to determine the weight w_i of each ETF. One (but by far not the only) way to fix these weights is as follows. First, as in the sector momentum rotation strategy, we compute cumulative returns R_i^{cum} (over some period T, e.g., 6-12 months). We only take ETFs with positive R_i^{cum}. If desired, optionally, we can further filter out ETFs as in the sector momentum rotation strategy with an MA filter, by keeping only the ETFs whose last closing prices P_i are higher than their corresponding long-term moving averages $\mathrm{MA}_i(T')$ (typically, the MA length T' is 100 to 200 days). Now, instead of taking ETFs in the top decile by R_i^{cum} (as in the sector momentum rotation strategy), we can assign nonzero weights w_i to all remaining ETFs, whose number in this context is relatively small to begin with by design. The weights can, e.g., be assigned as follows:

$$w_i = \gamma_1 \ R_i^{cum} \tag{371}$$
$$w_i = \gamma_2 \ R_i^{cum}/\sigma_i \tag{372}$$
$$w_i = \gamma_3 \ R_i^{cum}/\sigma_i^2 \tag{373}$$

Here: σ_i is the historical volatility; and the overall normalization coefficients $\gamma_1, \gamma_2, \gamma_3$ in each case are computed based on the requirement that $\sum_{i=1}^N w_i = 1$ (where N is the number of ETFs in our portfolio after all filters are applied, i.e., those with nonzero weights). Thus, the weights in Eq. (371) are simply proportional to the past cumulative returns R_i^{cum}, which are taken as the measure of momentum, so the expected returns are also given by (or, more precisely, proportional to) R_i^{cum}. The issue with this weighting scheme is that it overweighs volatile ETFs as on average $R_i^{cum} \propto \sigma_i$. The weights in Eq. (372) mitigate this, while the weights in Eq. (373) actually optimize the Sharpe ratio of the ETF portfolio assuming a diagonal covariance matrix $C_{ij} = \mathrm{diag}(\sigma_i^2)$ for the ETF returns, i.e., by ignoring their correlations.[83] Imposing bounds $w_i \leq w_i^{max}$ can further mitigate overweighing.

[83] For some literature on multi-asset portfolios, dynamic asset allocation and related topics, see, e.g., [Bekkers, Doeswijk and Lam, 2009], [Black and Litterman, 1992], [Detemple and Rindisbacher, 2010], [Doeswijk, Lam and Swinkels, 2014], [Faber, 2015], [Faber, 2016], [Mladina, 2014], [Petre,

5 Fixed Income

5.1 Generalities

5.1.1 Zero-coupon bonds

A promise of being paid \$1 at the maturity time T can be regarded as an asset, which has some worth at time t before T. This asset is called a (zero-coupon) *discount bond*. Let its price at time $0 \leq t \leq T$ be $P(t,T)$. Then $P(T,T) = 1$. The *yield* of a discount bond is defined as[84]

$$R(t,T) = -\frac{\ln(P(t,T))}{T-t} \tag{374}$$

and has the meaning of an average interest rate over the period of time $T-t$. The higher the bond price at time t, the lower the yield $R(t,T)$ and vice versa. Below we refer to a zero-coupon bond with a \$1 principal and maturity T as a T-bond.

5.1.2 Bonds with coupons

In practice, a bond usually pays not only its principal at maturity T, but also makes smaller coupon payments before maturity. Consider a bond that makes n regular coupon payments at a fixed *uncompounded* rate k at times $T_i = T_0 + i\delta$, $i = 1, 2, \dots, n$, and also pays \$1 principal at maturity T. The amount of each coupon payment is $k\delta$, where δ is the payment period. This income stream is equivalent to owning one T-bond plus $k\delta$ units of each T_i-bond, $i = 1, \dots, n$. The price of the coupon bond at time t then is

$$P_c(t,T) = P(t,T) + k\delta \sum_{i=I(t)}^{n} P(t,T_i) \tag{375}$$

where $I(t) = \min(i: \ t < T_i)$. At time $t = T_0$ we have

$$P_c(T_0,T) = P(T_0,T) + k\delta \sum_{i=1}^{n} P(T_0,T_i) \tag{376}$$

If we desire the coupon bond to start with its face value ($P_c(T_0,T) = 1$), then the corresponding coupon rate is given by

$$k = \frac{1 - P(T_0,T)}{\delta \sum_{i=1}^{n} P(T_0,T_i)} \tag{377}$$

2015], [Sassetti and Tani, 2006], [Sharpe, 2009], [Sharpe and Perold, 2009], [Sørensen, 1999], [Tripathi and Garg, 2016], [Wu, 2003], [Zakamulin, 2014b].

[84] More precisely, this definition assumes continuous compounding. For periodic compounding at n discrete times $T_i = T_0 + i\delta$, $i = 1, \dots, n$, the yield between $t = T_0$ and $t = T_n$ is given by $R(T_0,T_n) = \delta^{-1}\left([P(T_0,T_n)]^{-1/n} - 1\right)$ assuming $P(T_n,T_n) = 1$, i.e., T_n is the maturity. Eq. (374) is recovered in the limit where $n \to \infty$, $\delta \to 0$, $n\delta =$ fixed (and equal to $T-t$ in Eq. (374)).

5.1.3 Floating rate bonds

A bond might also have *floating* coupon payments. Thus, consider a bond that pays \$1 at maturity T, and also makes coupon payments at times $T_i = T_0 + i\delta$, $i = 1, 2, \dots, n$, with amounts based on the variable rate (usually LIBOR – see Subsection 5.15)

$$L(T_{i-1}) = \frac{1}{\delta}\left[\frac{1}{P(T_{i-1}, T_i)} - 1\right] \tag{378}$$

The actual coupon payment at time T_i is

$$X_i = L(T_{i-1})\delta = \frac{1}{P(T_{i-1}, T_i)} - 1 \tag{379}$$

which is the amount of interest we would get by buying \$1's worth of a T_i-bond at time T_{i-1}. Indeed, a T_i-bond is worth $P(T_{i-1}, T_i)$ at $t = T_{i-1}$, so \$1's worth a T_i-bond at $t = T_{i-1}$ is worth $1/P(T_{i-1}, T_i)$ at $t = T_i$, so the interest earned is given by Eq. (379). The total value of the variable coupon bond at $t = T_0$ is given by:

$$V_0 = 1 - [P(T_0, T_n) - P(T_0, T)] \tag{380}$$

If $T = T_n$, then we have $V_0 = 1$. This is because this bond is equivalent to the following sequence of trades. At time $t = T_0$ take \$1 and buy T_1-bonds with it. At time $t = T_1$ take the interest from the T_1-bonds as the T_1-coupon, and buy T_2-bonds with the leftover \$1 principal. Repeat until we are left with \$1 at time T_n. This has exactly the same cash flow as the variable coupon bond, so the initial prices must match. If $T > T_n$, then $V_0 < 1$ and can be determined as follows. First, note that

$$V_0 = P(T_0, T) + V_0^{coupons} \tag{381}$$

where $V_0^{coupons}$ is the total value of all n coupon payments at $t = T_0$. This value is independent of T and is determined from

$$P(T_0, T_n) + V_0^{coupons} = 1 \tag{382}$$

which is the value of the variable coupon bond with maturity T_n. Hence Eq. (380).

5.1.4 Swaps

Swaps are contracts that exchange a stream of floating rate payments for a stream of fixed rate payments or vice versa. A swap where we receive a stream of fixed rate payments in exchange for floating rate payments is simply a portfolio which is long a fixed coupon bond and short a variable coupon bond. The price of the former at $t = T_0$ is given by Eq. (376), while that of the latter is given by Eq. (380). The fixed rate that gives the swap initial null value is independent of maturity T and given by

$$k = \frac{1 - P(T_0, T_n)}{\delta \sum_{i=1}^{n} P(T_0, T_i)} \tag{383}$$

5.1.5 Duration and convexity

Macaulay duration of a bond is a weighted average maturity of its cash flows, where the weights are the present values of said cash flows. E.g., for a fixed rate coupon bond we have (see Eq. (376))

$$\mathrm{MacD}(t,T) = \frac{1}{P_c(t,T)} \left[(T-t)\ P(t,T) + k\delta \sum_{i=I(t)}^{n} (T_i - t)\ P(t,T_i) \right] \tag{384}$$

Modified duration is defined as (assuming *parallel shifts* in the yield curve)[85]

$$\mathrm{ModD}(t,T) = -\frac{\partial \ln\left(P_c(t,T)\right)}{\partial R(t,T)} \tag{385}$$

For continuous compounding, Macaulay duration and modified duration are the same (see Eq. (374)). For periodic compounding, they differ. For a *constant* yield $R(t,\tau) = Y = \text{const.}$ (for all $t < \tau < T$), they are related via (see fn. 84):

$$\mathrm{ModD}(t,T) = \mathrm{MacD}(t,T)/(1+Y\delta) \tag{386}$$

Modified duration is a measure of the relative bond price sensitivity to changes in the interest rates: $\Delta P_c(t,T)/P_c(t,T) \approx -\mathrm{ModD}(t,T)\ \Delta R(t,T)$ (for parallel shifts $\Delta R(t,\tau) = \Delta R = \text{const.}$, for all $t < \tau < T$). Similarly, dollar duration defined as

$$\mathrm{DD}(t,T) = -\frac{\partial P_c(t,T)}{\partial R(t,T)} = \mathrm{ModD}(t,T)\ P_c(t,T) \tag{387}$$

is a measure of the absolute bond price sensitivity to changes in the interest rates.

Convexity of a bond is defined as (again, assuming parallel shifts)[86]

$$C(t,T) = -\frac{1}{P_c(t,T)}\ \frac{\partial^2 P_c(t,T)}{\partial R(t,T)^2} \tag{388}$$

and corresponds to nonlinear effects in the response of the bond price to interest rate changes:

$$\Delta P_c(t,T)/P_c(t,T) \approx -\mathrm{ModD}(t,T)\ \Delta R(t,T) + \frac{1}{2}\ C(t,T)\ [\Delta R(t,T)]^2 \tag{389}$$

[85] I.e., $\partial R(t,\tau)/\partial R(t,T) = 1$ for all $t < \tau < T$. For nonuniform shifts things get complicated.

[86] For some literature on various properties of bonds, see, e.g., [Baxter and Rennie, 1996], [Bessembinder and Maxwell, 2008], [Čerović *et al*, 2014], [Chance and Jordan, 1996], [Chen, Lesmond and Wei, 2007], [Chen, Mao and Wang, 2010], [Christensen, 1999], [Cole and Young, 1995], [Fabozzi, 2006a], [Fabozzi, 2012a], [Fabozzi, 2012b], [Fabozzi and Mann, 2010], [Henderson, 2003], [Horvath, 1998], [Hotchkiss and Ronen, 2002], [Hull, 2012], [Hull, Predescu and White, 2005], [Jostova *et al*, 2013], [Kakushadze, 2015a], [Leland and Panos, 1997], [Litterman and Scheinkman, 1991], [Macaulay, 1938], [Martellini, Priaulet and Priaulet, 2003], [Osborne, 2005], [Samuelson, 1945], [Stulz, 2010], [Tuckman and Serrat, 2015].

5.2 Strategy: Bullets

In a bullet portfolio, all bonds have the same maturity date T thereby targeting a specific segment of the yield curve. The maturity can be picked based on the trader's outlook on the future interest rates: if the interest rates are expected to fall (i.e., the bond prices to rise), then picking a longer maturity would make more sense; if the interest rates are expected to rise (i.e., the bond prices to fall), then a shorter maturity would be more warranted; however, if the trader is uncertain about the future interest rates, a more diversified portfolio (e.g., a barbell/ladder portfolio – see below) is in order (as opposed to a bullet portfolio). Typically, the bonds in a bullet portfolio are purchased over time, which mitigates the interest rate risk to some extent: if the interest rates rise, the later bond purchases will be at higher rates; if the interest rates fall, the earlier bond purchases will have higher yields.[87]

5.3 Strategy: Barbells

In this strategy all purchased bonds are concentrated in two maturities T_1 (short maturity) and T_2 (long maturity), so this portfolio is a combination of two bullet strategies. This strategy takes advantage of the higher yields from the long-maturity bonds while hedging the interest rate risk with the short-maturity bonds: if the interest rates rise, the long-maturity bonds will lose value, but the proceeds from the short-maturity bonds can be reinvested at higher rates.[88] The modified duration (call it D) of the barbell strategy is the same as the modified duration (call it D_*) of a bullet strategy with a mid-range maturity (call it T_*, $T_1 < T_* < T_2$). However, the convexity (call it C) of the barbell strategy is higher than the convexity (call it C_*) of this bullet strategy. Intuitively this can be understood by noting that modified duration scales approximately linearly with maturity, while convexity scales approximately quadratically with maturity. For illustrative purposes and simplicity, let us consider a barbell strategy consisting of w_1 dollars' worth of zero-coupon bonds with short maturity T_1 and w_2 dollars' worth of zero-coupon bonds with long maturity T_2 (each bond has \$1 face value). Furthermore, let us assume continuous compounding and a constant yield Y. We then have

$$D = \frac{\widetilde{w}_1\ T_1 + \widetilde{w}_2\ T_2}{\widetilde{w}_1 + \widetilde{w}_2} \tag{390}$$

$$T_* = D_* = D \tag{391}$$

$$C = \frac{\widetilde{w}_1\ T_1^2 + \widetilde{w}_2\ T_2^2}{\widetilde{w}_1 + \widetilde{w}_2} \tag{392}$$

$$C_* = T_*^2 \tag{393}$$

[87] For some literature on bullet and barbell (see below) strategies, see, e.g., [Fabozzi, Martellini and Priaulet, 2006], [Grantier, 1988], [Jones, 1991], [Mann and Ramanlal, 1997], [Pascalau and Poirier, 2015], [Su and Knowles, 2010], [Wilner, 1996], [Yamada, 1999].

[88] Flattening/steepening of the yield curve (the spread between the short-term and long-term interest rates decreases/increases) has a positive/negative impact on the value of the portfolio.

where $\widetilde{w}_1 = w_1 \exp(-T_1 Y)$ and $\widetilde{w}_2 = w_2 \exp(-T_2 Y)$. Straightforward algebra gives

$$C - C_* = \frac{\widetilde{w}_1 \widetilde{w}_2}{(\widetilde{w}_1 + \widetilde{w}_2)^2} (T_2 - T_1)^2 > 0 \qquad (394)$$

Higher convexity of the barbell portfolio provides a better protection against parallel shifts in the yield curve. However, this comes at the expense of a lower overall yield.

5.4 Strategy: Ladders

A ladder is a bond portfolio with (roughly) equal capital allocations into bonds of n different maturities T_i, $i = 1, \dots, n$ (where the number of rungs n is sizable, e.g., $n = 10$). The maturities are equidistant: $T_{i+1} = T_i + \delta$. This is a duration-targeting strategy,[89] which maintains an approximately constant duration by selling shorter-maturity bonds as they approach maturity and replacing them with new longer-maturity bonds. A ladder portfolio aims to diversify the interest rate and reinvestment risks[90] by avoiding exposure to only a few maturities (as in bullets and barbells). It also generates a regular revenue stream from the coupons of each bond. The maturity of a ladder portfolio can be defined as the average maturity:

$$T = \frac{1}{n} \sum_{i=1}^{n} T_i \qquad (395)$$

The income is higher for higher values of T; however, so is the interest rate risk.

5.5 Strategy: Bond immunization

Bond immunization is used in cases such as a predetermined future cash obligation. A simple solution would be to purchase a zero-coupon bond with the required maturity (and desirable/acceptable yield). However, such a bond may not always be available in the market, so a portfolio of bonds with varying maturities must be used instead. Such a portfolio is subject to the interest rate and reinvestment risks. One way to mitigate these risks is to build a portfolio whose duration matches the maturity of the future cash obligation (thereby "immunizing" the bond portfolio against parallel shifts in the yield curve). Consider a portfolio of bonds with 2 different maturities T_1, T_2 and the corresponding durations D_1, D_2 (where "duration" means modified duration). Let: the dollar amounts invested in these bonds be P_1, P_2; the total amount to be invested be P; the desired duration of the portfolio be D (which

[89] For some literature on ladder and duration-targeting strategies, see, e.g., [Bierwag and Kaufman, 1978], [Bohlin and Strickland, 2004], [Cheung, Kwan and Sarkar, 2010], [Dyl and Martin, 1986], [Fridson and Xu, 2014], [Judd, Kubler and Schmedders, 2011], [Langetieg, Leibowitz and Kogelman, 1990], [Leibowitz and Bova, 2013], [Leibowitz, Bova and Kogelman, 2014], [Leibowitz, Bova and Kogelman, 2015].

[90] The reinvestment risk is the risk that the proceeds (from coupon payments and/or principal) would be reinvested at a lower rate than the original investment.

is related to the maturity T_* of the future cash obligation – see below); and the *constant* yield (which is assumed to be *the same for all bonds* – see below) be Y. Then P is fixed using Y and the amount of the future obligation F:

$$P = F/(1+Y\delta)^{T_*/\delta} \tag{396}$$

where we are assuming periodic compounding and δ is the length of each compounding period (e.g., 1 year).[91] Then we have:

$$P_1 + P_2 = P \tag{397}$$
$$P_1\ D_1 + P_2\ D_2 = P\ D \tag{398}$$

where

$$D = T_*/(1+Y\delta) \tag{399}$$

With 3 bonds, we can also match the convexity:

$$P_1 + P_2 + P_3 = P \tag{400}$$
$$P_1\ D_1 + P_2\ D_2 + P_3\ D_3 = P\ D \tag{401}$$
$$P_1\ C_1 + P_2\ C_2 + P_3\ C_3 = P\ C \tag{402}$$

where C_1, C_2, C_3 are the convexities of the 3 bonds and

$$C = T_*(T_* + \delta)/(1+Y\delta)^2 \tag{403}$$

In practice, the yield curve changes over time, which (among other things) requires that the portfolio be periodically rebalanced. This introduces nontrivial transaction costs, which must also be accounted for. Furthermore, the yields are not the same for all bonds in the portfolio, which introduces additional complexity into the problem.[92]

5.6 Strategy: Dollar-duration-neutral butterfly

This is a zero-cost combination of a long barbell portfolio (with short T_1 and long T_3 maturities) and a short bullet portfolio (with a medium maturity T_2, where $T_1 < T_2 < T_3$). Let: the dollar amounts invested in the 3 bonds be P_1, P_2, P_3; and

[91] For the sake of simplicity, in Eq. (396) the number $n = T_*/\delta$ of compounding periods is assumed to be a whole number. Extension to non-integer T_*/δ is straightforward.

[92] For some literature on bond immunization, including more sophisticated optimization techniques, see, e.g., [Albrecht, 1985], [Alexander and Resnick, 1985], [Bierwag, 1979], [Bodie, Kane and Marcus, 1996], [Boyle, 1978], [Christensen and Fabozzi, 1985], [De La Peña, Garayeta and Iturricastillo, 2017], [Fisher and Weil, 1971], [Fong and Vasicek, 1983], [Fong and Vasicek, 1984], [Hürlimann, 2002], [Hürlimann, 2012], [Iturricastillo and De La Peña, 2010], [Khang, 1983], [Kocherlakota, Rosenbloom and Shiu, 1988], [Kocherlakota, Rosenbloom and Shiu, 1990], [Montrucchio and Peccati, 1991], [Nawalkha and Chambers, 1996], [Reddington, 1952], [Reitano, 1996], [Shiu, 1987], [Shiu, 1988], [Zheng, Thomas and Allen, 2003].

the corresponding modified durations be D_1, D_2, D_3. Then zero cost (i.e., dollar-neutrality) and the dollar-duration-neutrality (the latter protects the portfolio from parallel shifts in the yield curve) imply that

$$P_1 + P_3 = P_2 \tag{404}$$
$$P_1\ D_1 + P_3\ D_3 = P_2\ D_2 \tag{405}$$

This fixes P_1, P_3 via P_2. While the portfolio is immune to parallel shifts in the yield curve, it is not immune to changes in the slope or the curvature of the yield curve.[93]

5.7 Strategy: Fifty-fifty butterfly

This is a variation of the standard butterfly. In the above notations for the dollar-duration-neutral butterfly, we have

$$P_1\ D_1 = P_3\ D_3 = \frac{1}{2}\ P_2\ D_2 \tag{406}$$

So, the fifty-fifty butterfly is still dollar-duration-neutral, but it is no longer dollar-neutral (i.e., it is not a zero-cost strategy). Instead, dollar durations of the wings are the same (hence the term "fifty-fifty"). As a result, the strategy is (approximately) neutral to small steepening and flattening of the yield curve, to wit, if the interest rate spread change between the body and the short-maturity wing is equal to the spread change between the long-maturity wing and the body. That is why this strategy is a.k.a. "neutral curve butterfly" (whose cost is non-dollar-neutrality).

5.8 Strategy: Regression-weighted butterfly

Empirically, short-term interest rates are sizably more volatile than long-term interest rates.[94] Therefore, the interest rate spread change between the body and the short-maturity wing (of the butterfly – see above) can be expected to be greater by some factor – call it β – than the spread change between the long-maturity wing and the body (so, typically $\beta > 1$). This factor can be obtained from historical data via, e.g., running a regression of the spread change between the body and the short-maturity wing over the spread change between the long-maturity wing and the body. Then, instead of Eq. (406), we have the following dollar-duration-neutrality and "curve-neutrality" conditions:

$$P_1\ D_1 + P_3\ D_3 = P_2\ D_2 \tag{407}$$
$$P_1\ D_1 = \beta\ P_3\ D_3 \tag{408}$$

[93] For some literature on various butterfly bond strategies, see, e.g., [Bedendo, Cathcart and El-Jahel, 2007], [Brooks and Moskowitz, 2017], [Christiansen and Lund, 2005], [Fontaine and Nolin, 2017], [Gibson and Pritsker, 2000], [Grieves, 1999], [Heidari and Wu, 2003], [Martellini, Priaulet and Priaulet, 2002].

[94] See, e.g., [Edwards and Susmel, 2003], [Joslin and Konchitchki, 2018], [Mankiw and Summers, 1984], [Shiller, 1979], [Sill, 1996], [Turnovsky, 1989].

5.8.1 Strategy: Maturity-weighted butterfly

This is a variation of the regression-weighted butterfly, where instead of fixing β in Eq. (408) via a regression based on historical data, this coefficient is based on the 3 bond maturities:

$$\beta = \frac{T_2 - T_1}{T_3 - T_2} \tag{409}$$

5.9 Strategy: Low-risk factor

As in stocks, empirical evidence suggests that lower-risk bonds tend to outperform higher-risk bonds on the risk-adjusted basis ("low-risk anomaly").[95] One can define "riskiness" of a bond using different metrics, e.g., bond credit rating and maturity. For instance, a long portfolio can be built (see, e.g., [Houweling and van Vundert, 2017]) by taking Investment Grade bonds with credit ratings AAA through A-, and then taking the bottom decile by maturity. Similarly, one can take High Yield bonds with credit ratings BB+ through B-, and then take the bottom decile by maturity.

5.10 Strategy: Value factor

"Value" for bonds (see, e.g., [Correia, Richardson and Tuna, 2012], [Houweling and van Vundert, 2017], [L'Hoir and Boulhabel, 2010]) is trickier to define than for stocks. One way is to compare the observed credit spread[96] to a theoretical prediction therefor. One way to estimate the latter is, e.g., via a linear cross-sectional (across N bonds labeled by $i = 1, \dots, N$) regression [Houweling and van Vundert, 2017]:

$$S_i = \sum_{r=1}^{K} \beta_r \, I_{ir} + \gamma \, T_i + \epsilon_i \tag{410}$$

$$S_i^* = S_i - \epsilon_i \tag{411}$$

Here: S_i is the credit spread; I_{ir} is a dummy variable ($I_{ir} = 1$ if the bond labeled by i has credit rating r; otherwise, $I_{ir} = 0$) for bond credit rating r (which labels K credit ratings present among the N bonds, which can be one of the 21 credit ratings);[97] T_i are bond maturities; β_r, γ are the regression coefficients; ϵ_i are the regression residuals; and S_i^* is the fitted (theoretical) value of the credit spread. The $N \times K$ matrix I_{ir} has no columns with all zeros (so K can be less than 21). Note that by definition, since each bond has one and only one credit rating, we have

$$\sum_{r=1}^{K} I_{ir} = 1 \tag{412}$$

[95] For some literature, see, e.g., [De Carvalho *et al*, 2014], [Derwall, Huij and De Zwart, 2009], [Frazzini and Pedersen, 2014], [Houweling and van Vundert, 2017], [Ilmanen, 2011], [Ilmanen *et al*, 2004], [Kozhemiakin, 2007], [Ng and Phelps, 2015].

[96] Credit spread is the difference between the bond yield and the risk-free rate.

[97] These credit ratings are AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, BBB-, BB+, BB, BB-, B+, B, B-, CCC+, CCC, CCC-, CC, C.

so the intercept is subsumed in I_{ir} (which is why there is no separate regression coefficient for the intercept). Next, value is defined as $V_i = \ln(S_i/S_i^*)$ or $V_i = \epsilon_i/S_i^* = S_i/S_i^* - 1$, and the bonds in the top decile by V_i are selected for the portfolio.

5.11 Strategy: Carry factor

Carry is defined as the return from the appreciation of the bond value as the bond rolls down the yield curve (see, e.g., [Beekhuizen *et al*, 2016], [Koijen, Moskowitz, Pedersen and Vrugt, 2018]):[98]

$$C(t, t+\Delta t, T) = \frac{P(t+\Delta t, T) - P(t, T)}{P(t, T)} \tag{413}$$

Here Δt is the period over which carry is computed. A simplification arises if we assume that the entire term structure of the interest rates stays constant, i.e., the yield $R(t,T) = f(T-t)$ is a function of only $T-t$ (i.e., time to maturity). Then, at time $t+\Delta t$ the yield is $R(t+\Delta t, T) = R(t, T-\Delta t)$. So, we have[99]

$$\begin{aligned} C(t, t+\Delta t, T) &= \frac{P(t+\Delta t, T)|_{R(t+\Delta t, T)} - P(t, T)|_{R(t,T)}}{P(t, T)|_{R(t,T)}} = \\ &= R(t,T)\,\Delta t + C_{roll}(t, t+\Delta t, T) \end{aligned} \tag{414}$$

where (taking into account the definition of the modified duration, Eq. (385))

$$\begin{aligned} C_{roll}(t, t+\Delta t, T) &= \frac{P(t+\Delta t, T)|_{R(t, T-\Delta t)} - P(t+\Delta t, T)|_{R(t,T)}}{P(t, T)|_{R(t,T)}} \approx \\ &\approx -\mathrm{ModD}(t,T)\,[R(t, T-\Delta t) - R(t,T)] \end{aligned} \tag{415}$$

So, if the term structure of the interest rates is constant, then carry $C(t, t+\Delta t, T)$ receives two contributions: i) $R(t,T)\,\Delta t$ from the bond yield; and ii) $C_{roll}(t, t+\Delta t, T)$ from the bond rolling down the yield curve. A zero-cost strategy can be built, e.g., by buying bonds in the top decile by carry and selling bonds in the bottom decile.

5.12 Strategy: Rolling down the yield curve

The objective of this strategy is to capture the "roll-down" component $C_{roll}(t, t+\Delta t, T)$ of bond yields. These returns are maximized in the steepest segments of the yield curve. Therefore, the trader can, e.g., buy long- or medium-term bonds from

[98] Here, for the sake of simplicity, we consider zero-coupon bonds. The end-result below is also valid for coupon bonds.

[99] For financed portfolios, $R(t,T)$ in the second line of Eq. (414) is replaced by $R(t,T) - r_f$, where r_f is the risk-free rate. However, this overall shift does not affect the actual holdings in the carry strategy below.

such segments and hold them while they are "rolling down the curve".[100] The bonds must be sold as they approach maturity and the proceeds can be used to buy new long/medium-term bonds from the steepest segment of the yield curve at that time.

5.13 Strategy: Yield curve spread (flatteners & steepeners)

This strategy consists of buying or selling the yield curve spread.[101] The yield curve spread is defined as the difference between the yields of two bonds of the same issuer with different maturities. If the interest rates are expected to fall, the yield curve is expected to steepen. If the interest rates are expected to rise, the yield curve is expected to flatten. The yield curve spread strategy can be summarized via the following rule:

$$\text{Rule} = \begin{cases} \text{Flattener: Short spread if interest rates are expected to rise} \\ \text{Steepener: Buy spread if interest rates are expected to fall} \end{cases} \tag{416}$$

Shorting the spread amounts to selling shorter-maturity bonds (a.k.a. the front leg) and buying longer-maturity bonds (a.k.a. the back leg). Buying the spread is the opposite trade: buying the front leg and selling the back leg. If the yield curve has parallel shifts, this strategy can generate losses. Matching dollar durations of the front and back legs immunizes the portfolio to small parallel shifts in the yield curve.

5.14 Strategy: CDS basis arbitrage

A credit default swap (CDS) is insurance against default on a bond.[102] The CDS price, known as the CDS spread, is a periodic (e.g., annual) premium per dollar of the insured debt. The CDS essentially makes the bond a risk-free instrument. Therefore, the CDS spread should equal the bond yield spread, i.e., the spread between the bond yield and the risk-free rate. The difference between the CDS spread and the bond spread is known as the CDS basis:

$$\text{CDS basis} = \text{CDS spread} - \text{bond spread} \tag{417}$$

[100] For some literature on the "rolling down the yield curve" strategies, see, e.g., [Ang, Alles and Allen, 1998], [Bieri and Chincarini, 2004], [Bieri and Chincarini, 2005], [Dyl and Joehnk, 1981], [Grieves *et al*, 1999], [Grieves and Marcus, 1992], [Osteryoung, McCarty and Roberts, 1981], [Pantalone and Platt, 1984], [Pelaez, 1997].

[101] For some literature on yield curve spread strategies, the yield curve dynamics and related topics, see, e.g., [Bernadell, Coche and Nyholm, 2005], [Boyd and Mercer, 2010], [Chua, Koh and Ramaswamy, 2006], [Diebold and Li, 2002], [Diebold, Rudebusch and Aruoba, 2006], [Dolan, 1999], [Evans and Marshall, 2007], [Füss and Nikitina, 2011], [Jones, 1991], [Kalev and Inder, 2006], [Krishnamurthy, 2002], [Shiller and Modigliani, 1979].

[102] For some literature on CDS basis arbitrage and related topics, see, e.g., [Bai and Collin-Dufresne, 2013], [Choudhry, 2004], [Choudhry, 2006], [Choudhry, 2007], [De Wit, 2006], [Fontana, 2010], [Fontana and Scheicher, 2016], [Kim, Li and Zhang, 2016], [Kim, Li and Zhang, 2017], [Nashikkar, Mahanti, 2011], [Rajan, McDermott and Roy, 2007], [Wang, 2014], [Zhu, 2006].

Negative basis indicates that the bond spread is too high relative to the CDS spread, i.e., the bond is relatively cheap. The CDS arbitrage trade then amounts to buying the bond and insuring it with the CDS[103] thereby generating a risk-free profit.[104]

5.15 Strategy: Swap-spread arbitrage

This dollar-neutral strategy consists of a long (short) position in an interest rate swap (see Subsection 5.1.4) and a short (long) position in a Treasury bond (with the constant yield $Y_{Treasury}$) with the same maturity as the swap. A long (short) swap involves receiving (making) fixed rate r_{swap} coupon payments in exchange for making (receiving) variable rate coupon payments at LIBOR (the London Interbank Offer Rate) $L(t)$. The short (long) position in the Treasury bond generates (is financed at) the "repo rate" (the discount rate at which the central bank repurchases government securities from commercial banks) $r(t)$ in a margin account. The per-dollar-invested rate $C(t)$ at which this strategy generates P&L is given by

$$C(t) = \pm[C_1 - C_2(t)] \quad (418)$$

$$C_1 = r_{swap} - Y_{Treasury} \quad (419)$$

$$C_2(t) = L(t) - r(t) \quad (420)$$

where the plus (minus) sign corresponds to the long (short) swap strategy. The long (short) swap strategy is profitable if LIBOR falls (rises). So, this is a LIBOR bet.[105]

6 Indexes

6.1 Generalities

An index is a diversified portfolio of assets combined with some weights. The underlying assets are often stocks, e.g., in indexes such as DJIA, S&P 500, Russell 3000, etc. DJIA weights are based on price, while S&P 500 and Russell 3000 weights are based on market capitalization. Investment vehicles such as index futures, index-based ETFs, etc., allow gaining exposure to a broad index with a single trade.[106]

[103] Note that the CDS is equivalent to a synthetic short bond position.

[104] In the case of positive basis, theoretically one would enter into the opposite trade, i.e., selling the bond and selling the CDS. However, in practice this would usually imply that the trader already owns the bond and the CDS, i.e., this would amount to unwinding an existing position.

[105] For some literature on swap spreads and related topics, see, e.g., [Asgharian and Karlsson, 2008], [Aussenegg, Götz and Jelic, 2014], [Chen and Selender, 1994], [Collin-Dufresne and Solnik, 2001], [Duarte, Longstaff and Yu, 2006], [Dubil, 2011], [Duffie, 1996], [Duffie and Singleton, 1997b], [Feldhütter and Lando, 2008], [Fisher, 2002], [Jermann, 2016], [Jordan and Jordan, 1997], [Kambhu, 2006], [Keane, 1996], [Klingler and Sundaresan, 2016], [Kobor, Shi and Zelenko, 2005], [Lang, Litzenberger and Liu, 1998], [Liu, Longstaff and Mandell, 2006)], [Minton, 1997].

[106] For some literature on indexes, see, e.g., [Antoniou and Holmes, 1995], [Beneish and Whaley, 1996], [Bologna and Cavallo, 2002], [Bos, 2000], [Chang, Cheng and Pinegar, 1999], [Chiang and

6.2 Strategy: Cash-and-carry arbitrage

This strategy (a.k.a. "index arbitrage") aims to exploit price inefficiencies between the index spot[107] price and index futures price.[108] Theoretically, the price of the index futures must equal the spot price accounting for the cost of carry during the life of the futures contract:

$$F^*(t,T) = [S(t) - D(t,T)] \exp\left(r\,(T-t)\right) \tag{421}$$

Here: $F^*(t,T)$ is the theoretical ("fair") price, at time t, of the futures contract with the delivery time T; $S(t)$ is the spot value at time t; $D(t,T)$ is the sum of (discounted values of) the dividends paid by the underlying stocks between the time t and delivery; and r is the risk-free rate, which for the sake of simplicity is assumed to be constant from t to delivery.[109] The basis is defined as

$$B(t,T) = \frac{F(t,T) - F^*(t,T)}{S(t)} \tag{422}$$

where $F(t,T)$ is the current price of the futures contract with the delivery time T. If $B(t,T) \neq 0$, more precisely, if $|B(t,T)|$ exceeds the pertinent transaction costs of executing the arbitrage trade, then there is an arbitrage opportunity. If the basis is positive (negative), the futures price is rich (cheap) compared with the spot price, so the arbitrage trade amounts to selling (buying) the futures and buying (selling) the cash (i.e., the index basket).[110] The position is closed when the basis goes to zero, i.e., the futures price converges to its fair value. Such arbitrage opportunities are short-lived and with the advent of high frequency trading require extremely fast execution. In many cases, the slippage can be prohibitive to execute the trade.[111]

6.3 Strategy: Dispersion trading in equity indexes

This strategy takes long positions on volatilities of the index constituents and a short position on index volatility. It is rooted in an empirical observation that, for

Wang, 2002], [Edwards, 1988], [Frino *et al*, 2004], [Graham and Pirie, 1994], [Hautcoeur, 2006], [Illueca and Lafuente, 2003], [Kenett *et al*, 2013], [Lamoureux and Wansley, 1987], [Larsen and Resnick, 1998], [Lo, 2016], [Schwartz and Laatsch, 1991], [Spyrou, 2005], [Yo, 2001].

[107] "Spot" refers to the current value of the index based on the current prices of its constituents. "Cash" refers to the underlying index portfolio. This is common trader lingo.

[108] See, e.g., [Brenner, Subrahmanyam and Uno, 1989], [Bühler and Kempf, 1995], [Butterworth and Holmes, 2010], [Chan and Chung, 1993], [Cornell and French, 1983], [Dwyer, Locke and Yu, 1996], [Fassas, 2011], [Puttonen, 1993], [Richie, Daigler and Gleason, 2008], [Yadav and Pope, 1990], [Yadav and Pope, 1994].

[109] Eq. (421) further ignores some other pertinent aspects such as taxes, asymmetry of interest rates (for long and short holdings), transaction costs, etc.

[110] Selling the futures poses no issues. However, selling the cash can be problematic with short-selling issues such as hard-to-borrow securities, etc. Continuously maintaining a sizable dollar-neutral book which is long cash and short futures can help circumvent such issues.

[111] In some cases incomplete baskets approximating the index can be executed to reduce the transaction costs, e.g., in market cap weighted indexes, by omitting lower cap (and thus less liquid) stocks. However, such mishedges also increase the risk of losing money on the trade.

the most part,[112] the implied volatility $\widetilde{\sigma}_I$ from index options is sizably higher than the theoretical index volatility σ_I given by

$$\sigma_I^2 = \sum_{i,j=1}^{N} w_i w_j \sigma_i \sigma_j \rho_{ij} \tag{423}$$

where w_i are the weights of the stocks in the index, σ_i are their implied volatilities from single-stock options, and ρ_{ij} is the sample correlation matrix ($\rho_{ii} = 1$)[113] computed based on a time series of historical returns.[114] Put differently, the index options are priced higher than the price corresponding to the aforesaid theoretical volatility. So, a basic strategy can be structured as follows. For each stock in the index we have a long position in n_i (near-ATM) single-stock option straddles (whose payoffs are based on the stock prices P_i), and we have a short position in a (near-ATM) option straddle for the index (whose payoff is based on the index level P_I – see below), where

$$n_i = \frac{S_i P_I}{\sum_{i=1}^{N} S_i P_i} \tag{424}$$

Here: S_i is shares outstanding for stock i (we are assuming the index is market cap weighted); and P_I is the index level. With this definition of n_i, we have $P_I = \sum_{i=1}^{N} n_i P_i$, so the index option straddle payoff matches the individual single-stock option straddle payoffs as closely as possible.[115] All options have approximately 1 month until the expiration, and all positions remain open until the expiration.[116]

6.3.1 Strategy: Dispersion trading – subset portfolio

For some indexes, some component stocks may not have single-stock options. Often these would be less liquid, lower market cap stocks. They would have to be excluded

[112] But not always – see below. For some literature on index vs. constituent volatilities and dispersion and correlation trading, see, e.g., [Carrasco, 2007], [Deng, 2008], [Lozovaia and Hizhniakova, 2005], [Marshall, 2008], [Marshall, 2009], [Maze, 2012], [Meissner, 2016], [Nelken, 2006].

[113] Note that the pair-wise correlations ρ_{ij}, $i \neq j$, typically are unstable out-of-sample, which can introduce a sizable error into this computation.

[114] For some pertinent literature, see, e.g., [Bakshi and Kapadia, 2003a], [Bakshi and Kapadia, 2003b], [Bakshi, Kapadia and Madan, 2003], [Bollen and Whaley, 2004], [Branger and Schlag, 2004], [Coval and Shumway, 2001], [Dennis and Mayhew, 2002], [Dennis, Mayhew and Stivers, 2006], [Driessen, Maenhout and Vilkov, 2009], [Gârleanu, Pedersen and Poteshman, 2009], [Lakonishok *et al*, 2007].

[115] If ATM options are not available for a given stock, OTM options (close to ATM) can be used.

[116] This strategy can be argued to be a volatility strategy. However, it can also be argued to be correlation trading as the volatility of the portfolio depends on the correlations between its components (see Eq. (423)). Thus, when the implied index volatility $\widetilde{\sigma}_I$ is higher than the theoretical value σ_I, this can be (arguably) interpreted as the implied average pair-wise correlation being higher than the average pair-wise correlation based on ρ_{ij}. In this regard, at times the index implied volatility can be lower than its theoretical value, so the dispersion strategy that is short index volatility would lose money and the reverse trade might be in order. See, e.g., [Deng, 2008].

from the bought portfolio. Reducing the number of bought underlying single-stock options is also desirable to reduce transaction costs. Furthermore, the sample correlation matrix ρ_{ij} is singular for a typical lookback period (e.g., daily close-to-close returns, going back 1 year, which is about 252 trading days) as the number of assets is large (500 for S&P 500 and even larger for other indexes). As mentioned above, the pair-wise correlations are unstable out-of-sample, which increases errors in the theoretical value σ_I computed via Eq. (423). This can be mitigated as follows.[117]

The singular and unstable correlation matrix can be made nonsingular and more stable by replacing it with a statistical risk model [Kakushadze and Yu, 2017a]. Let $V_i^{(A)}$ be the principal components of ρ_{ij} with the eigenvalues $\lambda^{(A)}$ in the decreasing order, $\lambda^{(1)} > \lambda^{(2)} > \lambda^{(r)}$, where r is the rank of ρ_{ij} (if $r < N$, the other eigenvalues are null: $\lambda^{(A)} = 0$, $A > r$). The statistical risk model correlation matrix is given by

$$\psi_{ij} = \xi_i^2 \; \delta_{ij} + \sum_{A=1}^{K} \lambda^{(A)} \; V_i^{(A)} \; V_j^{(A)} \tag{425}$$

$$\xi_i^2 = 1 - \sum_{A=1}^{K} \lambda^{(A)} \left[V_i^{(A)}\right]^2 \tag{426}$$

where $K < r$ is the number of risk factors based on the first K principal components that are chosen to explain systematic risk, and ξ_i is the specific (a.k.a. idiosyncratic) risk. The simplest way to fix K is via eRank (effective rank) [Roy and Vetterli, 2007] – see [Kakushadze and Yu, 2017a] for details and complete source code for constructing ψ_{ij} and fixing K. So, now we can use ψ_{ij} (instead of ρ_{ij}) to compute the theoretical volatility σ_I:

$$\sigma_I^2 = \sum_{i,j=1}^{N} w_i w_j \sigma_i \sigma_j \psi_{ij} = \sum_{i=1}^{N} w_i^2 \sigma_i^2 \xi_i^2 + \sum_{A=1}^{K} \left[\sum_{i=1}^{N} \lambda^{(A)} V_i^{(A)} w_i \sigma_i\right]^2 \tag{427}$$

The first term on the r.h.s. of Eq. (427) is due to the specific risk. The long portfolio then contains only the straddles corresponding to the first N_* single-stock options with the lowest N_* values of $w_i^2 \sigma_i^2 \xi_i^2$. E.g., for S&P 500 we can take $N_* = 100$.

6.4 Strategy: Intraday arbitrage between index ETFs

This strategy amounts to exploiting short-term mispricings between two ETFs (call them ETF1 and ETF2) on the same underlying index.[118] It can be summarized as

[117] The variation of the dispersion trading strategy we discuss here is similar but not identical to the PCA (principal component analysis) based strategy discussed in [Deng, 2008], [Larsson and Flohr, 2011], [Su, 2006]. The statistical risk model construction (see below) is more streamlined.

[118] E.g., S&P 500 ETFs, SPDR Trust (ticker SPY) and iShares (ticker IVV). See, e.g., [Marshall, Nguyen and Visaltanachoti]. For some additional literature on ETF arbitrage and related topics, see, e.g., [Abreu and Brunnermeier, 2002], [Ackert and Tian, 2000], [Ben-David, Franzoni and Moussawi, 2012], [Brown, Davies and Ringgenberg, 2018], [Cherry, 2004], [Dolvin, 2009], [Garvey and Wu, 2009], [Hendershott and Moulton, 2011], [Johnson, 2008], [Maluf and Albuquerque, 2013].

follows:

$$\text{Rule} = \begin{cases} \text{Buy ETF2, short ETF1} & \text{if } P_1^{Bid} \geq P_2^{Ask} \times \kappa \\ \text{Liquidate position} & \text{if } P_2^{Bid} \geq P_1^{Ask} \\ \text{Buy ETF1, short ETF2} & \text{if } P_2^{Bid} \geq P_1^{Ask} \times \kappa \\ \text{Liquidate position} & \text{if } P_1^{Bid} \geq P_2^{Ask} \end{cases} \tag{428}$$

Here: κ is a predefined threshold, which is close to 1, e.g., $\kappa = 1.002$ (see, e.g., [Marshall, Nguyen and Visaltanachoti]); P_1^{Bid} and P_2^{Bid} are the bid prices for ETF1 and ETF2, and P_1^{Ask} and P_2^{Ask} are the ask prices. Marketable "fill or kill" limit orders can be used to execute the trades. Such arbitrage opportunities are ephemeral and require a fast order execution system or else slippage will eat away the profits.

6.5 Strategy: Index volatility targeting with risk-free asset

A volatility targeting strategy aims to maintain a constant volatility level, which can be achieved by a periodic (weekly, monthly, etc.) rebalancing between a risky asset – in this case an index – and a riskless asset (e.g., U.S. Treasury bills).[119] If σ is the volatility of the risky asset[120] and the volatility target is σ_*, then the allocation weight for the risky asset is given by[121] $w = \sigma_*/\sigma$, and the allocation weight for the risk-free asset is $1 - w$. To avoid overtrading and reduce transaction costs, rebalancing (instead of periodically) can be done based, e.g., on a preset threshold κ, say, only if the percentage change $|\Delta w|/w$ since the last rebalancing exceeds κ.

7 Volatility

7.1 Generalities

Some option trading strategies discussed in Section 2 are volatility strategies, in the sense that they make bets on high or low future volatility.[122] There are various ways to make volatility bets, and volatility can be viewed as an asset class of its own. Historical volatility is based on a time series of past returns. In contrast, implied volatility extracted from options is considered a forward-looking measure of volatility.[123] VIX (CBOE Volatility Index, a.k.a. the "uncertainty index" or the

[119] For some pertinent literature, see, e.g., [Albeverio, Steblovskaya and Wallbaum, 2013], [Anderson, Bianchi and Goldberg, 2014], [Cirelli *et al*, 2017], [Cooper, 2010], [Giese, 2012], [Khuzwayo and Maré, 2014], [Kim and Enke, 2016], [Kirby and Ostdiek, 2012], [Papageorgiou, Reeves and Sherris, 2017], [Perchet, de Carvalho and Moulin, 2014], [Torricelli, 2018], [Zakamulin, 2014b].

[120] Usually, this is implied volatility as opposed to historical volatility as the former is considered to be forward-looking. Alternatively, it can be based on various volatility-forecasting techniques.

[121] If there is a preset maximum leverage L, then w is capped at L.

[122] E.g., long (short) straddles bet on increasing (decreasing) volatility.

[123] See, e.g., [Abken and Nandi, 1996], [Ané and Labidi, 2001], [Canina and Figlewski, 1993], [Christensen and Prabhala, 1998], [Derman and Kani, 1994], [Dumas, Fleming and Whaley, 1998],

"fear gauge index")[124] and other volatility indexes[125] and derivatives (options and futures) on volatility indexes such as VIX provide avenues for volatility trading.

7.2 Strategy: VIX futures basis trading

This is essentially a mean-reversion strategy. It is rooted in empirical observations (see, e.g., [Mixon, 2007], [Nossman and Wilhelmsson, 2009], [Simon and Campasano, 2014])[126] that the VIX futures basis (defined below) has essentially no forecasting power for subsequent VIX changes but has substantial forecasting power for subsequent VIX futures price changes. The VIX futures basis B_{VIX} (for our purposes here) is defined as

$$B_{VIX} = P_{UX1} - P_{VIX} \tag{429}$$

$$D = \frac{B_{VIX}}{T} \tag{430}$$

Here: P_{UX1} is the price of the first-month contract VIX futures;[127] P_{VIX} is the VIX price; D is the daily roll value; and T is the number of business days until the settlement (which is assumed to be at least 10). Empirically, the futures prices tend to fall for positive basis and rise for negative basis (mean-reversion). So, the strategy amounts to shorting VIX futures when the VIX futures curve is upward-sloping (a.k.a. "contango", so the basis is positive), and buying VIX futures when the VIX futures curve is downward-sloping (a.k.a. "backwardation", so the basis is negative). Here is a simple trading rule (see, e.g., [Simon and Campasano, 2014]):

$$\text{Rule} = \begin{cases} \text{Open long UX1 position} & \text{if } D < -0.10 \\ \text{Close long UX1 position} & \text{if } D > -0.05 \\ \text{Open short UX1 position} & \text{if } D > 0.10 \\ \text{Close short UX1 position} & \text{if } D < 0.05 \end{cases} \tag{431}$$

A short (long) UX1 position is exposed to a risk of a sudden increase (decrease) in the volatility, which typically occurs during equity market sell-offs (rallies), so this risk can be hedged by, e.g., shorting (buying) mini-S&P 500 futures.[128] The hedge

[Dupire, 1994], [Glasserman and Wu, 2010], [He, Hsu and Rue, 2015], [Lamoureux and Lastrapes, 1993], [Mayhew, 1995], [Skiadopoulos, Hodges and Clewlow, 1999].

[124] See, e.g., [Äijö, 2008], [Corrado and Miller, 2005], [Fleming, Ostdiek and Whaley, 1995], [Maghrebi, Kim and Nishina, 2007], [Shaikh and Padhi, 2015], [Siriopoulos and Fassas, 2009], [Skiadopoulos, 2004], [Whaley, 2000], [Whaley, 2009].

[125] E.g., RVX (CBOE Russell 2000 Volatility Index), VXEEM (CBOE Emerging Markets ETF Volatility Index), TYVIX (CBOE/CBOT 10-year U.S. Treasury Note Volatility Index), GVZ (CBOE Gold ETF Volatility Index), EUVIX (CBOE/CME FX Euro Volatility Index), VXGOG (CBOE Equity VIX on Google), VVIX (CBOE VIX of VIX Index), etc.

[126] For some additional literature on VIX futures basis and related topics, see, e.g., [Buetow and Henderson, 2016], [Donninger, 2014], [Fu, Sandri and Shackleton, 2016], [Lee, Liao and Tung, 2017], [Zhang, Shu and Brenner, 2010], [Zhang and Zhu, 2006].

[127] UX1 has approximately 1 month to maturity, UX2 has approximately 2 months, etc.

[128] Typically, VIX and the equity markets are anti-correlated.

ratio can be estimated, e.g., based on a historical serial regression of the VIX futures price changes over the front-month mini-S&P 500 futures contract returns.[129]

7.3 Strategy: Volatility carry with two ETNs

VXX is an exchange-traded note (ETN) that tracks VIX via a portfolio of short-maturity (months 1 and 2) VIX futures contracts. To maintain a constant maturity, at the close of each day, a portion of the shorter-maturity futures is sold and replaced with the longer-maturity futures bought with the proceeds. Since the VIX futures curve is in contango most of the time, the longer-maturity futures are priced higher than the shorter-maturity futures, so this rebalancing amounts to a decay in the value of VXX over time, which is known as the roll (or contango) loss. Further, as time passes, the futures converge to the spot (VIX), so VXX loses value so long as the VIX futures curve is in contango. VXZ is yet another ETN that tracks VIX via a portfolio of medium-maturity (months 4 through 7) VIX futures. VXZ also suffers roll loss, but to a lesser degree than VXX as the slope of the VIX futures curve in contango decreases with maturity.[130] The basic strategy then is to short VXX and buy VXZ with the hedge ratio that can be determined via a serial regression.[131] This strategy is not without risks, however. There can be short-term spikes in VXX (the corresponding spikes in VXZ usually are sizably smaller), which can lead to substantial short-term P&L drawdowns, even if the strategy is overall profitable.

7.3.1 Strategy: Hedging short VXX with VIX futures

Instead of using a long position in VXZ to hedge the short position in VXX, one can directly use a basket of, e.g., medium-maturity VIX futures.[132] The N VIX futures have some weights w_i. These weights can be fixed in a variety of ways, e.g., by minimizing the tracking error, i.e., by running a serial regression (with the intercept) of VXX returns over the N futures returns. Then we have:

$$w_i = \sigma_X \sum_{j=1}^{N} C^{-1}_{ij} \sigma_j \rho_j \tag{432}$$

[129] See, e.g., [Simon and Campasano, 2014] for details.

[130] For some literature on volatility ETNs and related topics, see, e.g., [Alexander and Korovilas, 2012], [Avellaneda and Papanicolaou, 2018], [DeLisle, Doran and Krieger, 2014], [Deng, McCann and Wang, 2012], [Eraker and Wu, 2014], [Gehricke and Zhang, 2018], [Grasselli and Wagalath, 2018], [Hancock, 2013], [Husson and McCann, 2011], [Liu and Dash, 2012], [Liu, Pantelous and von Mettenheim, 2018], [Moran and Dash, 2007].

[131] We have $h = \beta = \rho\sigma_X/\sigma_Z$, where: h (known as the optimal hedge ratio) is the number of VXZ to buy for each VXX shorted; β is the coefficient (for the VXZ returns) of the serial regression (with the intercept) of the VXX returns over the VXZ returns; σ_X and σ_Z are the historical volatilities of VXX and VXZ, respectively; and ρ is the pair-wise historical correlation between VXX and VXZ.

[132] These can have maturities of, e.g., 4 through 7 months (thus mimicking the VXZ composition).

Here: ρ_i is the pair-wise historical correlation between the futures labeled by i and VXX; C_{ij} is the $N \times N$ sample covariance matrix for the N futures ($\sigma_i^2 = C_{ii}$ is the historical variance for the futures labeled by i); and σ_X is the historical volatility of VXX. Some w_i may turn out to be negative. This is not necessarily an issue, but one may wish to impose the bounds $w_i \geq 0$. Further, one may wish the strategy to be dollar-neutral, which would amount to imposing the constraint

$$\sum_{i=1}^{N} w_i = 1 \tag{433}$$

which the optimal hedge ratios (432) generally do not satisfy. Also, instead of minimizing the tracking error, one may wish to minimize the variance of the entire portfolio. And so on. The portfolio can be rebalanced monthly or more frequently.

7.4 Strategy: Volatility risk premium

Empirical evidence indicates that implied volatility tends to be higher than realized volatility most of the time, which is known as the "volatility risk premium".[133] Simply put, most of the time options are priced higher than the prices one would expect based on realized volatility, so the idea is to sell volatility. E.g., the trader can sell straddles based on S&P 500 options. As a possible proxy for volatility risk premium, the trader can, e.g., use the difference between VIX at the beginning of the current month and the realized volatility (in %, as VIX is quoted in %) of S&P 500 daily returns since the beginning of the current month. If the spread is positive, the trader sells the straddle. If the volatility spikes (which usually happens if the market sells of), the strategy will lose money. It is profitable in sideways markets.[134]

7.4.1 Strategy: Volatility risk premium with Gamma hedging

The ATM straddles in the above strategy are Delta-neutral.[135] So, this is a "Vega play", i.e., the trader is shorting Vega. If the underlying (S&P 500) moves, the short straddle is no longer Delta-neutral: if the underlying goes up (down), Delta becomes negative (positive). So a variation of this strategy is to use Gamma hedging to keep the strategy close to Delta-neutral, which is achieved by buying (selling) the underlying if it moves up (down). Then this becomes a "Theta play", i.e., the

[133] For some pertinent literature, see, e.g., [Bakshi and Kapadia, 2003a], [Bollerslev, Gibson and Zhou, 2011], [Carr and Wu, 2009], [Carr and Wu, 2016], [Christensen and Prabhala, 1998], [Eraker, 2009], [Ge, 2016], [Miao, Wei and Zhou 2012], [Prokopczuk and Simen, 2014], [Saretto and Goyal, 2009], [Todorov, 2010].

[134] Also, index options are better suited for this strategy than single-stock options as index options typically have higher volatility risk premia (see Subsection 6.3).

[135] Some of the Greeks for options are: $\Theta = \partial V/\partial t$ (Theta), $\Delta = \partial V/\partial S$ (Delta), $\Gamma = \partial^2 V/\partial S^2$ (Gamma), $\nu = \partial V/\partial \sigma$ (Vega). Here: V is the value of the option; t is time; S is the price of the underlying; σ is the implied volatility.

strategy now aims to capitalize on the Theta-decay of the value of the sold options. So, the price of this is the cost of the Gamma hedging, which reduces the P&L. As the underlying moves more and more away from the strike of the sold put and call options, the Gamma hedge becomes more and more expensive and eventually will exceed the collected option premia, at which point the strategy starts losing money.

7.5 Strategy: Volatility skew – long risk reversal

OTM put options with the underlying at $S_0 = K + \kappa$ tend to be priced higher than OTM call options with the underlying at $S_0 = K - \kappa$ (here K is the strike price, and $\kappa > 0$ is the distance from the strike). I.e., with all else being equal, the implied volatility for puts is higher than for calls.[136] The long risk reversal strategy (see Subsection 2.12), where the trader buys an OTM call option and sells an OTM put option, captures this skew. However, this is a directional strategy – it loses money if the price of the underlying drops below $K_{put} - C$, where K_{put} is the strike price of the put, and $C > 0$ is the premium of the put minus the premium of the call.

7.6 Strategy: Volatility trading with variance swaps

One issue with trading volatility using options is the need to (almost continuously) Delta-hedge the position to avoid directional exposure,[137] which practically can be both cumbersome and costly. To avoid the need for Delta-hedging, one can make volatility bets using variance swaps. A variance swap is a derivative contract whose payoff $P(T)$ at maturity T is proportional to the difference between the realized variance $v(T)$ of the underlying and the preset variance strike K:

$$P(T) = N \times (v(T) - K) \tag{434}$$

$$v(T) = \frac{F}{T} \sum_{t=1}^{T} R^2(t) \tag{435}$$

$$R(t) = \ln\left[\frac{S(t)}{S(t-1)}\right] \tag{436}$$

Here: $t = 0, 1, \dots, T$ labels sample points (e.g., trading days); $S(t)$ is the price of the underlying at time t; $R(t)$ is the log-return from $t-1$ to t; F is the annualization factor (thus, if t labels trading days, then $F = 252$); and N is the "variance notional", which is preset. Note that in Eq. (435) the mean of $R(t)$ over the period $t = 1$ to $t = T$ is not subtracted, hence T in the denominator.[138] Long (short) variance swap

[136] For some pertinent literature, see, e.g., [Bondarenko, 2014], [Chambers *et al*, 2014], [Corrado and Su, 1997], [Damghani and Kos, 2013], [DeMiguel *et al*, 2013], [Doran and Krieger, 2010], [Doran, Peterson and Tarrant, 2007], [Fengler, Herwartz and Werner, 2012], [Flint and Maré, 2017], [Jackwerth, 2000], [Kozhan, Neuberger and Schneider, 2013], [Liu and van der Heijden, 2016], [Mixon, 2011], [Zhang and Xiang, 2008].

[137] See Subsection 7.4.1 for a Delta-hedging strategy (a.k.a. "Gamma scalping").

[138] If the mean is subtracted, then the denominator would be $T - 1$ instead.

is a bet that the future realized volatility will be higher (lower) than the current implied volatility. Long (short) variance swaps can therefore be used instead of, e.g., long (short) straddles to go long (short) volatility. For instance, the dispersion strategy of Subsection 6.3 can be executed by selling a variance swap on an index and buying variance swaps on the index constituents (cf. selling and buying straddles).[139]

8 Foreign Exchange (FX)

8.1 Strategy: Moving averages with HP filter

In Subsection 3.12 we discussed a trading strategy for stocks wherein the trading signal is based on 2 intersecting (shorter and longer) moving averages. A similar approach can be applied to FX as well. However, FX spot rate time series tend to be rather noisy, which can lead to false signals based on moving averages. To mitigate this, before computing the moving averages, the higher-frequency noise can first be filtered out, e.g., using the so-called Hodrick-Prescott (HP) filter.[140] Then, the remaining lower-frequency trend component (as opposed to the raw spot rate) can be used to compute the moving averages and generate the trading signal (see, e.g., [Harris and Yilmaz, 2009]). The HP filter is given by:

$$S(t) = S^*(t) + \nu(t) \tag{437}$$

$$g = \sum_{t=1}^{T} [S(t) - S^*(t)]^2 + \lambda \sum_{t=2}^{T-1} [S^*(t+1) - 2S^*(t) + S^*(t-1)]^2 \tag{438}$$

$$g \to \min \tag{439}$$

Here: the objective function g is minimized w.r.t. the set of T values of $S^*(t)$, $t = 1, \dots, T$; $S(t)$ is the FX spot rate at time t; $S^*(t)$ is the lower-frequency ("regular") component; $\nu(t)$ is the higher-frequency ("irregular") component, which is treated as noise; the first term in Eq. (438) minimizes the noise, while the second term (based on the discretized second derivative of $S^*(t)$) penalizes the variation in $S^*(t)$; and λ is the smoothing parameter. There is no "fundamental" method to fix λ. Sometimes (but not always) it is set to $\lambda = 100 \times n^2$, where n is the data frequency measured on

[139] For some literature on variance swaps, see, e.g., [Aït-Sahalia, Karaman and Mancini, 2015], [Bernard, Cui and Mcleish, 2014], [Broadie and Jain, 2008], [Bossu, 2006], [Carr and Lee, 2007], [Carr and Lee, 2009], [Carr, Lee and Wu, 2012], [Demeterfi *et al*, 1999], [Elliott, Siu and Chan, 2007], [Filipović, Gourier and Mancini, 2016], [Hafner and Wallmeier, 2007], [Härdle and Silyakova, 2010], [Jarrow *et al*, 2013], [Konstantinidi and Skiadopoulos, 2016], [Leontsinis and Alexander, 2016], [Liverance, 2010], [Martin, 2011], [Rujivan and Zhu, 2012], [Schoutens, 2005], [Wystup and Zhou, 2014], [Zhang, 2014], [Zheng and Kwok, 2014].

[140] A.k.a. the Whittaker-Henderson method in actuarial sciences. For some pertinent literature, see, e.g., [Baxter and King, 1999], [Bruder *et al*, 2013], [Dao, 2014], [Ehlgen, 1998], [Harris and Yilmaz, 2009], [Harvey and Trimbur, 2008], [Henderson, 1924], [Henderson, 1925], [Henderson, 1938], [Hodrick and Prescott, 1997], [Joseph, 1952], [Lahmiri, 2014], [Mcelroy, 2008], [Weinert, 2007], [Whittaker, 1923], [Whittaker, 1924].

an annual basis (see, e.g., [Baxter and King, 1999] for more detail). So, for monthly data, which is what is usually used in this context, $n = 12$. The estimation period usually spans several years (of monthly data). Once $S^*(t)$ is determined, two moving averages $\mathrm{MA}(T_1)$ and $\mathrm{MA}(T_2)$, $T_1 < T_2$, are calculated based on $S^*(t)$. Then, as before, $\mathrm{MA}(T_1) > \mathrm{MA}(T_2)$ is a buy signal, and $\mathrm{MA}(T_1) < \mathrm{MA}(T_2)$ is a sell signal.

8.2 Strategy: Carry trade

Pursuant to "Uncovered Interest Rate Parity" (UIRP), excess interest earned in one country compared with another country due to a differential between risk-free interest rates in these countries would be precisely offset by depreciation in the FX rate between their currencies:

$$(1 + r_d) = \frac{E_t(S(t+T))}{S(t)}\ (1 + r_f) \qquad (440)$$

Here: r_d is the domestic interest rate; r_f is the foreign interest rate; both r_d and r_f are assumed to be constant over the compounding period T; $S(t)$ is the spot FX rate at time t, which is the worth of 1 unit of the foreign currency in units of the domestic currency; and $E_t(S(t+T))$ is the future (at time $t+T$) spot FX rate expected at time t.[141] UIRP does not always hold, giving rise to trading opportunities – which are *not* risk-free arbitrage opportunities (see below). Thus, UIRP implies that high interest rate currencies should depreciate w.r.t. low interest rate currencies, whereas empirically on average the opposite tends to transpire, i.e., such currencies tend to appreciate (somewhat).[142] So, the basic carry strategy amounts to writing (i.e., selling) forwards on currencies that are at a forward premium, i.e., the forward FX rate $F(t,T)$ exceeds the spot FX rate $S(t)$, and buying forwards on currencies that are at a forward discount, i.e., the forward FX rate $F(t,T)$ is lower than the spot FX rate $S(t)$.[143] The forward FX rate is given by[144]

$$F(t,T) = S(t)\ \frac{1 + r_d}{1 + r_f} \qquad (441)$$

[141] Thus, 1 USD invested at time t in a risk-free asset in the U.S. would be forth $(1 + r_d)$ USD at time $t+T$. Alternatively, 1 USD would buy $1/S(t)$ JPY at time t, which sum could be invested in a risk-free asset in Japan at time t, which would be worth $(1/S(t)) \times (1 + r_f)$ JPY at time $t+T$, which in turn could be expected to be exchanged for $(E_t(S(t+T))/S(t)) \times (1 + r_f)$ USD at time $t+T$. Requiring that the U.S. and Japan investments yield the same return gives Eq. (440).

[142] This is known as "forward premium/discount anomaly/puzzle" or "Fama puzzle". For some literature on UIRP and related topics, see, e.g., [Anker, 1999], [Ayuso and Restoy, 1996], [Bacchetta and van Wincoop, 2006], [Bacchetta and van Wincoop, 2010], [Baillie and Osterberg, 2000], [Bekaert, Wei and Xing, 2007], [Beyaert, García-Solanes, and Pérez-Castejón, 2007], [Bilson, 1981], [Chaboud and Wright, 2005], [Engel, 1996], [Fama, 1984], [Frachot, 1996], [Froot and Thaler, 1990], [Hansen and Hodrick, 1980], [Harvey, 2015], [Hodrick, 1987], [Ilut, 2012], [Lewis, 1995], [Lustig and Verdelhan, 2007], [Mark and Wu, 2001], [Roll and Yan, 2008].

[143] Ignoring transaction costs, this is equivalent to borrowing (lending) low (high) interest rate currencies without hedging the FX rate risk.

[144] This is known as "Covered Interest Rate Parity" (CIRP). Note that, assuming Eq. (441) holds (see below), when UIRP (i.e., Eq. (440)) does not hold, $F(t,T) \neq E_t(S(t+T))$.

As mentioned above, the carry strategy[145] is not without risks: this trade can generate losses if the borrowed (lent) currency suddenly appreciates (depreciates) w.r.t. its counterpart, i.e., it is exposed to the FX rate risk. On the other hand, if we borrow the low interest rate currency with the maturity date T, invest the funds in the high interest rate currency, and hedge this position with a forward contract to exchange the high interest rate currency for the low interest rate currency at maturity T (so we can cover the loan), ignoring the transaction costs (and other subtleties such as taxes, etc.), this is a risk-free position and any gains therefrom would amount to risk-free arbitrage. Hence Eq. (441), which is a no-risk-free-arbitrage condition.[146]

8.2.1 Strategy: High-minus-low carry

The carry strategy discussed above can be applied to individual foreign currencies. It can also be applied cross-sectionally, to multiple foreign currencies. Let $s(t) = \ln(S(t))$ (log spot FX rate) and $f(t,T) = \ln(F(t,T))$ (log forward FX rate). The forward discount $D(t,T)$ is defined as

$$D(t,T) = s(t) - f(t,T) \tag{442}$$

Pursuant to CIRP, Eq. (441), we have

$$D(t,T) = \ln\left(\frac{1+r_f}{1+r_d}\right) \approx r_f - r_d \tag{443}$$

For a positive forward discount, we buy a forward (i.e., borrow the domestic currency and invest in the foreign currency), and the higher the forward discount, the more profitable the strategy. For a negative forward discount, we sell a forward (i.e., borrow the foreign currency and invest in the domestic currency), and the lower the forward discount, the more profitable the strategy. So, we can construct a cross-sectional trade (including a zero-cost, i.e., dollar-neutral trade – see, e.g., [Lustig, Roussanov and Verdelhan, 2011]) by buying forwards on currencies in some top quantile[147] by forward discount and selling forwards on currencies in the corresponding bottom quantile. The forwards can, e.g., be one-month forwards.

[145] For some literature on currency carry trades and related topics, see, e.g., [Bakshi and Panayotov, 2013], [Brunnermeier, Nagel and Pedersen, 2008], [Burnside *et al*, 2011], [Burnside, Eichenbaum and Rebelo, 2007], [Burnside, Eichenbaum and Rebelo, 2008], [Clarida, Davis and Pedersen, 2009], [Deardorff, 1979], [Doskov and Swinkels, 2015], [Hau, 2014], [Jurek, 2014], [Lustig, Roussanov and Verdelhan, 2011], [Lustig, Roussanov and Verdelhan, 2014], [Olmo and Pilbeam, 2009], [Ready, Roussanov and Ward, 2017], [Rhee and Chang, 1992].

[146] Nonetheless, deviations from CIRP (i.e., Eq. (441)) do occur, which gives rise to covered interest arbitrage. See, e.g., [Akram, Rime and Sarno, 2008], [Avdjiev *et al*, 2016], [Baba and Packer, 2009], [Boulos and Swanson, 1994], [Clinton, 1988], [Coffey, Hrung and Sarkar, 2009], [Cosandier and Lang, 1981], [Du, Tepper and Verdelhan, 2018], [Duffie, 2017], [Frenkel and Levich, 1975], [Frenkel and Levich, 1981], [Liao, 2016], [Mancini-Griffoli and Ranaldo, 2011], [Popper, 1993], [Rime, Schrimpf and Syrstad, 2017].

[147] Unlike stocks, that number in thousands, there is a limited number of currencies to play with. Therefore, one does not necessarily have the luxury of taking top and bottom deciles by forward discount. So, this quantile can be a half, a third, etc., depending on the number of currencies.

8.3 Strategy: Dollar carry trade

This strategy is based on the average cross-sectional forward discount $\overline{D}(t,T)$ (see, e.g., [Lustig, Roussanov and Verdelhan, 2014]) for a basket of N foreign currencies:

$$\overline{D}(t,T) = \frac{1}{N}\sum_{i=1}^{N} D_i(t,T) \tag{444}$$

where $D_i(t,T)$ is the forward discount for the currency labeled by $i = 1,\dots,N$. This strategy then goes long (short), with equal weights, all N foreign currency forwards when $\overline{D}(t,T)$ is positive (negative), where T can be $1, 2, 3, 6, 12$ months. Empirical evidence suggests that this strategy relates to the state of the U.S. economy, to wit, when the U.S. economy is weak, the average forward discount tends to be positive.[148]

8.4 Strategy: Momentum & carry combo

This is a combination of the momentum strategy (Subsection 8.1)[149] and the carry strategy (Subsection 8.2), or their variations. There is a variety of ways these strategies can be combined (including an equally weighted combo, or some ideas discussed in, e.g., Subsection 3.6 and Subsection 4.6). A simple combination is based on minimizing the variance of the combo strategy using the sample covariance matrix of historical returns $R_1(t_s)$ and $R_2(t_s)$ of the two strategies (see, e.g., [Olszweski and Zhou, 2013]). Let (here Var and Cor are serial variance and correlation, respectively)

$$\sigma_1^2 = \mathrm{Var}(R_1(t_s)) \tag{445}$$

$$\sigma_2^2 = \mathrm{Var}(R_2(t_s)) \tag{446}$$

$$\rho = \mathrm{Cor}(R_1(t_s), R_2(t_s)) \tag{447}$$

Then minimizing the historical variance of the combined return $R(t_s)$ fixes the strategy weights w_1 and w_2:

$$R(t_s) = w_1\ R_1(t_s) + w_2\ R_2(t_s) \tag{448}$$

$$w_1 + w_2 = 1 \tag{449}$$

$$\mathrm{Var}(R(t_s)) \rightarrow \min \tag{450}$$

$$w_1 = \frac{\sigma_2^2 - \sigma_1\sigma_2\rho}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho} \tag{451}$$

$$w_2 = \frac{\sigma_1^2 - \sigma_1\sigma_2\rho}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho} \tag{452}$$

[148] See, e.g., [Cooper and Priestley, 2008], [Joslin and Konchitchki, 2018], [Joslin, Priebsch and Singleton, 2014], [Lustig, Roussanov and Verdelhan, 2014], [Stambaugh, 1988], [Tille, Stoffels and Gorbachev, 2001].

[149] For additional literature on FX momentum strategies and related topics, see, e.g., [Accominotti and Chambers, 2014], [Ahmerkamp and Grant, 2013], [Burnside, Eichenbaum and Rebelo, 2011], [Chiang and Jiang, 1995], [Grobys, Heinonen and Kolari, 2016], [Menkhoff *et al*, 2012], [Okunev and White, 2003], [Serban, 2010].

8.5 Strategy: FX triangular arbitrage

This strategy is based on 3 currency pairs.[150] Let these currencies be A, B and C. Then we have 2 chains: i) exchange A for B, exchange B for C, and exchange C for A; and ii) exchange A for C, exchange C for B, and exchange B for A. We will focus on the first chain as the second one is obtained by swapping B for C. Each currency pair has the bid and the ask; e.g., $Bid(A \to B)$ and $Ask(B \to A)$ for the A-B pair. So, the rate at which A is exchanged into B is $Bid(A \to B)$, while the rate at which B is exchanged into A is $1/Ask(B \to A)$. Therefore, $Bid(B \to A) = 1/Ask(B \to A)$, and $Ask(A \to B) = 1/Bid(A \to B)$. In the chain i) above, the trader starts with A and loops back to A with the overall exchange rate

$$R(A \to B \to C \to A) = Bid(A \to B) \times Bid(B \to C) \times \frac{1}{Ask(C \to A)} \qquad (453)$$

If this quantity is greater than 1, then the trader makes a profit. Such opportunities are ephemeral, so fast market data and trade execution systems are critical here.[151]

9 Commodities

9.1 Strategy: Roll yields

When commodity futures are in backwardation (contango), i.e., when the term structure of futures prices is downward (upward) sloping, long (short) futures positions on average generate positive returns due to the roll yield. Roll yields come from rebalancing futures positions: 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). Let

$$\phi = P_1/P_2 \qquad (454)$$

where P_1 is the front-month futures price, and P_2 is the second-month futures price. The ratio ϕ is a measure of backwardation ($\phi > 1$) and contango ($\phi < 1$). A zero-cost long-short portfolio can then be built based on ϕ, e.g., by buying commodity futures with higher values of ϕ and selling futures with lower values thereof.[152]

[150] Albeit one can also consider more than 3 pairs, which is known as multi-currency arbitrage (see, e.g., [Moosa, 2003a]).

[151] For some literature on triangular arbitrage and related topics, see, e.g., [Aiba and Hatano, 2006], [Aiba *et al*, 2002], [Aiba *et al*, 2003], [Akram, Rime and Sarno, 2008], [Choi, 2011], [Cross and Kozyakin, 2015], [Fenn *et al*, 2009], [Goldstein, 1964], [Gradojevic, Gençay and Erdemlioglu, 2017], [Ito *et al*, 2012], [Moosa, 2001], [Morisawa, 2009], [Mwangi and Duncan, 2012], [Osu, 2010].

[152] For some pertinent literature, see, e.g., [Anson, 1998], [Arnott *et al*, 2014], [Erb and Harvey, 2006], [Fama and French, 1987], [Fama and French, 1988], [Feldman and Till, 2006], [Fuertes, Miffre and Fernandez-Perez, 2015], [Gorton, Hayashi and Rouwenhorst, 2013], [Gorton and Rouwenhorst, 2006], [Greer, 2000], [Leung *et al*, 2016], [Ma, Mercer and Walker, 1992], [Mou, 2010], [Mouakhar and Roberge, 2010], [Symeonidis *et al*, 2012], [Taylor, 2016], [Telser, 1958].

9.2 Strategy: Trading based on hedging pressure

This strategy is based on hedgers' and speculators' position data provided (weekly) by the U.S. Commodity Futures Trading Commission (CFTC) in the Commitments of Traders (COT) reports. For each commodity, the "hedging pressure" (HP), separately for hedgers and speculators, is calculated as the number of long contracts divided by the total number of contracts (long plus short). So, HP is between 0 and 1. High (low) hedgers' HP is indicative of contango (backwardation), while high (low) speculators' HP is indicative of backwardation (contango). A zero-cost portfolio can be constructed, e.g., as follows. First, the cross-section of commodities is divided into the upper half and the lower half by the speculators' HP. Then, the upper half commodity futures are bought if they are in the bottom quintile by the hedgers' HP, and the lower half commodity futures are sold if they are in the top quintile by the hedger's HP. Typical formation and holding periods are 6 months.[153]

9.3 Strategy: Portfolio diversification with commodities

Commodity markets typically have a low correlation with equity markets, which can be used to improve performance characteristics of equity portfolios by combining equity and commodity investments. There are different ways to do this. A "passive approach" would amount to buying commodities with a preset portion of the available funds, holding them, and rebalancing the portfolio with some periodicity (e.g., monthly or annually). An "active approach" would amount to a tactical asset allocation approach via increasing/decreasing the exposure to commodities based on an increase/decrease in the Fed discount rate (empirically, commodity returns tend to be sizably correlated with the Fed monetary policy) or some other methodology.[154]

9.4 Strategy: Value

This strategy is similar to the value strategy for stocks (see Subsection 3.3). Value for commodities can be defined as, e.g., the ratio (see, e.g., [Asness, Moskowitz and

[153] For some literature on trading strategies based on such data and related topics, see, e.g., [Basu and Miffre, 2013], [Bessembinder, 1992], [Carter, Rausser and Schmitz, 1983], [Cheng and Xiong, 2013], [de Roon, Nijman and Veld, 2000], [Dewally, Ederington and Fernando, 2013], [Fernandez-Perez, Fuertes and Miffre, 2016], [Fishe, Janzen and Smith, 2014], [Fuertes, Miffre and Fernandez-Perez, 2015], [Hirshleifer, 1990], [Lehecka, 2013], [Miffre, 2012], [Switzer and Jiang, 2010].

[154] For some literature on diversification strategies using commodities and related topics, see, e.g., [Adams and Glück, 2015], [Bernardi, Leippold and Lohre, 2018], [Bjornson and Carter, 1997], [Blitz and Van Vliet, 2008], [Bodie, 1983], [Bodie and Rosansky, 1980], [Chan *et al*, 2011], [Chance, 1994], [Chong and Miffre, 2010], [Conover *et al*, 2010], [Creti, Joëts and Mignon, 2013], [Daumas, 2017], [Draper, Faff and Hillier, 2006], [Edwards and Park, 1996], [Elton, Gruber and Rentzler, 1987], [Frankel, 2006], [Gorton and Rouwenhorst, 2006], [Greer, 1978], [Greer, 2007], [Hess, Huang and Niessen, 2008], [Jensen, Johnson and Mercer, 2000], [Jensen, Johnson and Mercer, 2002], [Kaplan and Lummer, 1998], [Lummer and Siegel, 1993], [Marshall, Cahan and Cahan, 2008], [Miffre and Rallis, 2007], [Nguyen and Sercu, 2010], [Taylor, 2004], [Vrugt *et al*, 2007], [Wang and Yu, 2004], [Weiser, 2003].

Pedersen, 2013])

$$v = P_5/P_0 \tag{455}$$

where P_5 is the spot price 5 years ago,[155] and P_0 is the current spot price. Then one can build a zero-cost portfolio by, e.g., buying the commodities in the top tercile by value, and selling those in the bottom tercile. The portfolio is rebalanced monthly.

9.5 Strategy: Skewness premium

This strategy is based on the empirically observed negative correlation between the skewness of historical returns and future expected returns of the commodity futures. The skewness S_i is defined as ($i = 1, \dots, N$ labels different commodities):

$$S_i = \frac{1}{\sigma_i^3\, T} \sum_{s=1}^{T} \left[R_{is} - \overline{R}_i\right]^3 \tag{456}$$

$$\overline{R}_i = \frac{1}{T} \sum_{s=1}^{T} R_{is} \tag{457}$$

$$\sigma_i^2 = \frac{1}{T-1} \sum_{s=1}^{T} \left[R_{is} - \overline{R}_i\right]^2 \tag{458}$$

where R_{is} are the time series of historical returns (with T observations in each time series). A zero-cost strategy can be built by, e.g., buying the commodity futures in the bottom quintile by skewness, and selling the futures in the top quintile.[156]

9.6 Strategy: Trading with pricing models

Commodity futures term structure is nontrivial. One way to model it is via stochastic processes. Let $S(t)$ be the spot price, and let $X(t) = \ln(S(t))$. Then $X(t)$ can be modeled using, e.g., a mean-reverting Brownian motion (i.e., the Ornstein-Uhlenbeck process [Uhlenbeck and Ornstein, 1930]):[157]

$$dX(t) = \kappa \left[a - X(t)\right] dt + \sigma\, dW(t) \tag{459}$$

[155] Or the average spot price between 5.5 and 4.5 years ago.

[156] See, e.g., [Fernandez-Perez *et al*, 2018]. For some additional pertinent literature, see, e.g., [Barberis and Huang, 2008], [Christie-David and Chaudry, 2001], [Eastman and Lucey, 2008], [Gilbert, Jones and Morris 2006], [Junkus, 1991], [Kumar, 2009], [Lien, 2010], [Lien and Wang, 2015], [Mitton and Vorkink, 2007], [Stulz, 1996], [Tversky and Kahneman, 1992].

[157] This is a one-factor model. More complex models including multifactor models, nonconstant/stochastic volatility models, etc., can be considered instead. For some literature on modeling futures prices via stochastic processes and related topics, see, e.g., [Andersen, 2010], [Bessembinder *et al*, 1995], [Borovkova and Geman, 2006], [Casassus and Collin-Dufresne, 2005], [Chaiyapo and Phewchean, 2017], [Choi *et al*, 2014], [Geman and Roncoroni, 2006], [Gibson and Schwartz, 1990], [Hilliard and Reis, 1998], [Jankowitsch and Nettekoven, 2008], [Litzenberger and Rabinowitz, 1995], [Liu and Tang, 2011], [Milonas, 1991], [Miltersen and Schwartz, 1998], [Ng and Pirrong, 1994], [Nielsen and Schwartz, 2004], [Paschke and Prokopczuk, 2012], [Pindyck, 2001], [Routledge, Seppi and Spatt, 2000], [Schwartz, 1997], [Schwartz, 1998], [Schwartz and Smith, 2000].

Here the parameters κ (mean-reversion parameter), a (the long-run mean) and σ (log-volatility) are assumed to be constant; and $W(t)$ is a $\mathbf{Q}$-Brownian motion, where $\mathbf{Q}$ is a risk-free probability measure.[158] The standard claim pricing argument (see, e.g., [Baxter and Rennie, 1996], [Hull, 2012], [Kakushadze, 2015a]) gives for the futures price $F(t,T)$ (which is the price at time t of the futures contract with the delivery date T)

$$F(t,T) = E_t(S(T)) \tag{460}$$

$$\ln(F(t,T)) = E_t(X(T)) + \frac{1}{2}V_t(X(T)) \tag{461}$$

Here $E_t(\cdot)$ and $V_t(\cdot)$ are the conditional expectation and variance, respectively, at time t. This gives:

$$\begin{aligned} \ln(F(t,T)) &= \exp\left(-\kappa(T-t)\right) X(t) + a\left[1-\exp\left(-\kappa(T-t)\right)\right] + \\ &+ \frac{\sigma^2}{4\kappa}\left[1-\exp\left(-2\kappa(T-t)\right)\right] \end{aligned} \tag{462}$$

The parameters κ, a, σ can be fitted using historical data (e.g., using nonlinear least squares). Then the current market price can be compared to the model price to identify the futures that are rich (sell signal) and cheap (buy signal) compared with the model prediction. Here two cautionary remarks are in order. First, the model fit could work in-sample but have no predictive power out-of-sample, so the forecasting power needs to be ascertained (see, e.g., [Paschke and Prokopczuk, 2012]). Second, a priori we could write down any reasonable term structure model with desirable qualitative properties (e.g., mean-reversion) and fit the parameters using historical data without any reference to an underlying stochastic dynamics whatsoever, including using, e.g., "black-box" machine learning techniques. So long as the model works out-of-sample, there is no magic bullet here and "fancy" does not equal "better".

10 Futures

10.1 Strategy: Hedging risk with futures

Exposures to certain risks can be mitigated by hedging with futures. E.g., a grain trader who at time t anticipates that he or she will need to buy (sell) X tons of soy at a later time T can hedge the risk of soy prices increasing (decreasing) between t and T by buying (selling) at time t a futures contract with the delivery date T for the desired amount of soy. This simple strategy can have tweaks and variations.[159]

[158] Note that this model reduces to the Black-Scholes model [Black and Scholes, 1973] in the limit $\kappa \to 0$, $a \to \infty$, $\kappa\, a =$ fixed.

[159] For some literature on hedging with futures, see, e.g., [Ahmadi, Sharp and Walther, 1986], [Cheung, Kwan and Yip, 1990], [Ederington, 1979], [Géczy, Minton and Schrand, 1997], [Ghosh, 1993], [Grant, 2016], [Hanly, Morales and Cassells, 2018], [Lebeck, 1978], [Lien and Tse, 2000], [Mun, 2016], [Wolf, 1987], [Working, 1953].

10.1.1 Strategy: Cross-hedging

Sometimes a futures contract for the asset to be hedged may not be available. In such cases, the trader may be able to hedge using a futures contract for another asset with similar characteristics.[160] At maturity T, the payoff of the cross-hedged position established at time t (assuming the short futures position with the unit hedge ratio) is given by:

$$\begin{aligned} & S(T) - F(T,T) + F(t,T) = \\ & [S_*(T) - F(T,T)] + [S(T) - S_*(T)] + F(t,T) \end{aligned} \tag{463}$$

Here: the subscript $*$ indicates that the underlying asset of the futures contract is different from the hedged asset; $S(t)$ is the spot price; $F(t,T)$ is the futures price; the first term on the r.h.s. represents the basis risk stemming from the difference at delivery between the futures and the spot prices; and the second term represents the difference twixt the two underlying prices. In practice, the optimal hedge ratio may not be 1 and can be estimated via, e.g., a serial regression or some other method.[161]

10.1.2 Strategy: Interest rate risk hedging

Fixed-income assets are sensitive to interest rate variations (see Section 5) and futures contracts can be used to hedge the interest rate risk. A long (short) hedge position amounts to buying (selling) interest rate futures in order to hedge against an increase (decrease) in the price of the underlying asset, i.e., a decrease (increase) in the interest rates.[162] The corresponding P&L ($P_L(t,T)$ for the long hedge and $P_S(t,T)$ for the short hedge, assuming the position is established at $t = 0$ with the unit hedge ratio and the maturity is T) is given by:

$$P_L(t,T) = B(0,T) - B(t,T) \tag{464}$$

$$P_S(t,T) = B(t,T) - B(0,T) \tag{465}$$

$$B(t,T) = S(t) - F(t,T) \tag{466}$$

[160] For some literature on cross-hedging with futures, see, e.g., [Anderson and Danthine, 1981], [Ankirchner *et al*, 2012], [Ankirchner and Heyne, 2012], [Benet, 1990], [Blake and Catlett, 1984], [Blank, 1984], [Brooks, Davies and Kim, 2007], [Chen and Sutcliffe, 2007], [Dahlgran, 2000], [DeMaskey, 1997], [DeMaskey and Pearce, 1998], [Foster and Whiteman, 2002], [Franken and Parcell, 2003], [Hartzog, 1982], [Lafuente, 2013], [McEnally and Rice, 1979], [Mun and Morgan, 1997].

[161] For various optimal hedge ratio techniques, see, e.g., [Baillie and Myers, 1991], [Brooks and Chong, 2001], [Brooks, Henry and Persand, 2002], [Cecchetti, Cumby and Figlewski, 1988], [Davis, 2006], [Holmes, 1996], [Lien, 1992], [Lien, 2004], [Lien and Luo, 1993], [Lindahl, 1992], [Low *et al*, 2002], [Kroner and Sultan, 1993], [Monoyios, 2004], [Moosa, 2003b], [Myers, 1991].

[162] For some literature on hedging the interest rate risk with futures, see, e.g., [Booth, Smith and Stolz, 1984], [Briys and Solnik, 1992], [Čerović and Pepić, 2011], [Clare, Ioannides and Skinner, 2000], [Fortin and Khoury, 1984], [Gay, Kolb and Chiang, 1983], [Hilliard, 1984], [Hilliard and Jordan, 1989], [Ho and Saunders, 1983], [Kolb and Chiang, 1982], [Lee and Oh, 1993], [Pepić, 2014], [Picou, 1981], [Trainer, 1983], [Yawitz and Marshall, 1985], [Yeutter and Dew, 1982].

where $B(t,T)$ is the futures basis. In practice, the hedge ratio may not be 1. If a hedge is against a bond in the futures delivery basket,[163] then the conversion factor model[164] is commonly used to compute the hedge ratio h_C:

$$h_C = C\, \frac{M_B}{M_F} \tag{467}$$

where M_B is the nominal value of the bond, M_F is the nominal value of the futures, and C is the conversion factor. Unlike the conversion factor model, the modified duration hedge ratio h_D can be used for both deliverable and non-deliverable bonds:

$$h_D = \beta\, \frac{D_B}{D_F} \tag{468}$$

where D_B is the dollar duration[165] of the bond, D_F is the dollar duration of the futures, and β (which is often set to 1) is the change in the bond yield relative to the change in the futures yield, both taken for a given change in the risk-free rate.[166]

10.2 Strategy: Calendar spread

A bull (bear) futures spread amounts to buying (selling) a near-month futures and selling (buying) a deferred-month futures. This reduces exposure to the overall market volatility and allows to focus more on the fundamentals. Thus, for commodity futures, for the most part, near-month contracts react to supply and demand more than deferred-month contracts. Therefore, if the trader expects low (high) supply and high (low) demand, then the trader can make a bet with a bull (bear) spread.[167]

[163] Typically, an interest rate futures contract allows not just one bond but any bond from a predefined array of bonds (with varying maturities, coupons, etc.) to be delivered. Hence the use of the conversion factor (see below) defined as follows [Hull, 2012]: "The conversion factor for a bond is set equal to the quoted price the bond would have per dollar of principal on the first day of the delivery month on the assumption that the interest rate for all maturities equals 6% per annum (with semiannual compounding)."

[164] The conversion factor model applies only to futures contracts that use conversion factors, such as T-bond and T-note futures.

[165] Recall that the dollar duration equals the price times the modified duration.

[166] The factor β can be estimated based on the historical data. For some literature on interest rate futures hedge ratios and related topics, see, e.g., [Chang and Fang, 1990], [Chen, Kang and Yang, 2005], [Daigler and Copper, 1998], [Falkenstein and Hanweck, 1996], [Fisher and Weil, 1971], [Gay and Kolb, 1983], [Geske and Pieptea, 1987], [Grieves and Mann, 2004], [Grieves and Marcus, 2005], [Hegde, 1982], [Kolb and Chiang, 1981], [Kuberek and Pefley, 1983], [Landes, Stoffels and Seifert, 1985], [Pitts, 1985], [Rendleman, 1999], [Toevs and Jacob, 1986], [Viswanath, 1993].

[167] For some literature on futures calendar spreads and related topics, see, e.g., [Abken, 1989], [Adrangi *et al*, 2006], [Barrett and Kolb, 1995], [Bernstein, 1990], [Bessembinder, 1992], [Bessembinder, 1993], [Bessembinder and Chan, 1992], [Billingsley and Chance, 1988], [Castelino and Vora, 1984], [Cole *et al*, 1999], [Daigler, 2007], [de Roon, Nijman and Veld, 1998], [de Roon, Nijman and Veld, 2000], [Dunis, Laws and Evans, 2006], [Dunis, Laws and Evans, 2010], [Dutt *et al*, 1997], [Frino and McKenzie, 2002], [Girma and Paulson, 1998], [Hou and Nordén, 2018], [Kawaller, Koch and

10.3 Strategy: Contrarian trading (mean-reversion)

This strategy is similar to the mean-reversion strategy discussed in Subsection 3.9. Within a given universe of futures labeled by $i = 1, \dots, N$, the "market index" return is calculated as an equally weighted average:

$$R_m = \frac{1}{N} \sum_{i=1}^{N} R_i \tag{469}$$

where R_i are the individual futures returns (typically over the last one week). The capital allocation weights w_i then are given by

$$w_i = -\gamma \left[R_i - R_m\right] \tag{470}$$

where $\gamma > 0$ is fixed via the normalization condition

$$\sum_{i=1}^{N} |w_i| = 1 \tag{471}$$

Note that the strategy is automatically dollar-neutral. It amounts to buying losers and selling winners w.r.t. the market index (see, e.g., [Wang and Yu, 2004]).[168] As in the case of equities, the simple weighting scheme given by Eq. (470) is prone to overinvesting in volatile futures, which can be mitigated by suppressing w_i by $1/\sigma_i$ or $1/\sigma_i^2$, where σ_i are the historical volatilities. The portfolio is rebalanced weekly.

10.3.1 Strategy: Contrarian trading – market activity

Bells and whistles can be added to the above "basic" mean-reversion strategy by incorporating volume and open interest filters. Let V_i be the total volume for the futures labeled by i over the last week (i.e., the sum of daily volumes over the last week), and V_i' be the total volume over the prior week. Let U_i and U_i' be the analogous quantities for the open interest. Let

$$v_i = \ln(V_i/V_i') \tag{472}$$

$$u_i = \ln(U_i/U_i') \tag{473}$$

Then the strategy can be built, e.g., by taking the upper half of the futures by the volume factor v_i, taking the lower half of these futures by the open interest factor u_i, and applying the strategy defined by Eq. (470) to this subset of the futures.[169]

Ludan, 2002], [Kim and Leuthold, 1997], [McComas, 2003], [Moore, Toepke and Colley, 2006], [Ng and Pirrong, 1994], [Perchanok, 2012], [Perchanok and Kakabadse, 2013], [Poitras, 1990], [Ross, 2006], [Salcedo, 2004], [Schap, 2005], [Shimko, 1994], [Till and Eagleeye, 2017], [van den Goorbergh, 2004].

[168] For some additional pertinent literature, see, e.g., [Bali and Demirtas, 2008], [Bessembinder *et al*, 1995], [Bianchi, Drew and Fan, 2015], [Chaves and Viswanathan, 2016], [Fuertes, Miffre and Fernandez-Perez, 2015], [Irwin, Zulauf and Jackson, 1996], [Julio, Hassan and Ngene, 2013], [Leung *et al*, 2016], [Monoyios and Sarno, 2002], [Rao, 2011], [Rosales and McMillan, 2017], [Tse, 2017].

[169] The rationale behind this is that: i) larger volume changes are likely indicative of greater overreaction (see, e.g., [Bloom, Easley and O'Hara, 1994], [Conrad, Hameed and Niden, 2013],

10.4 Strategy: Trend following (momentum)

Various momentum strategies for futures can be constructed similarly to those for stocks. Here is a simple example (see, e.g., [Balta and Kosowski, 2013], [Moskowitz, Ooi and Pedersen, 2012]).[170] Let R_i be the returns for the futures labeled by $i = 1, \dots, N$ over the past period T (which can be measured in, e.g., days, weeks, or months). Then the weights w_i of the trading portfolio are given by

$$w_i = \gamma \, \frac{\eta_i}{\sigma_i} \tag{474}$$

$$\eta_i = \mathrm{sign}(R_i) \tag{475}$$

where σ_i are the historical volatilities (computed over the period T or some other period), and $\gamma > 0$ is fixed via the normalization condition

$$\sum_{i=1}^{N} |w_i| = 1 \tag{476}$$

Note that this strategy is equivalent to the optimization strategy (see Subsection 3.18, Eq. (350)) with a diagonal covariance matrix $C_{ij} = \sigma_i^2 \, \delta_{ij}$ (i.e., the correlations between different futures are ignored) and the expected returns $E_i = \eta_i \sigma_i$. This is to be contrasted with the expected returns based on the cumulative returns (Eq. (267)), which in this case equal R_i. One issue with using $E_i = \eta_i \sigma_i$ as opposed to $E_i = R_i$ is that, for small $|R_i|$ (e.g., compared with σ_i), η_i can flip even though the change in R_i is small. This results in an undesirable instability in the strategy. There are ways to mitigate this, e.g., by smoothing via $\eta_i = \tanh(R_i/\kappa)$, where κ is some parameter, e.g., the cross-sectional standard deviation of R_i (see, e.g., [Kakushadze, 2015b]). Alternatively, one may simply take $E_i = R_i$ (and further use a non-diagonal C_{ij}). Also, note that the weights defined by Eq. (474) are not dollar-neutral. This can be rectified by demeaning them:

$$w_i = \gamma \left[\frac{\eta_i}{\sigma_i} - \frac{1}{N} \, \sum_{j=1}^{N} \frac{\eta_j}{\sigma_j} \right] \tag{477}$$

One shortcoming of this is that now some futures with $\eta_i > 0$ may be sold, and some futures with $\eta_i < 0$ may be bought. To avoid this, if the number $N_+ = |H_+|$ of the

[DeBondt and Thaler, 1985], [Gervais and Odean, 2001], [Odean, 2002], [Statman, Thorley and Vorkink, 2006]), so a greater "snap-back" (i.e., mean-reversion) effect can be expected; and ii) open interest is related to trading by hedgers and is a proxy for market depth (see, e.g., [Bessembinder and Seguin, 1993]), so an increase in open interest is indicative of a deeper market where volume increases have smaller effects on prices as compared with when there is a decrease in open interest.

[170] For some additional pertinent literature, see, e.g., [Ahn *et al*, 2002], [Bianchi, Drew and Fan, 2015], [Dusak, 1973], [Fuertes, Miffre and Fernandez-Perez, 2015], [Fuertes, Miffre and Rallis, 2010], [Hayes, 2011], [Kazemi and Li, 2009], [Miffre and Rallis, 2007], [Pirrong, 2005], [Reynauld and Tessier, 1984], [Schneeweis and Gupta, 2006], [Szakmary, Shen and Sharma, 2010].

futures with $\eta_i > 0$ is not dramatically different from the number $N_- = |H_-|$ of the futures with $\eta_i < 0$ (here $H_\pm = \{i | \pm \eta_i > 0\}$), we can take the weights to be

$$w_i = \gamma_+ \frac{\eta_i}{\sigma_i}, \quad i \in H_+ \tag{478}$$

$$w_i = \gamma_- \frac{\eta_i}{\sigma_i}, \quad i \in H_- \tag{479}$$

So, now we have two parameters $\gamma_\pm$, which can be fixed to satisfy Eq. (476) and the dollar-neutrality condition

$$\sum_{i=1}^{N} w_i = 0 \tag{480}$$

However, if most η_i are positive (negative), i.e., we have skewed returns, then long (short) positions will be well-diversified, while the short (long) positions will not be. This can happen, e.g., if the broad market is rallying (selling off). Eq. (477) mitigates this to some extent. However, η_i can still be skewed in this case. A simple way to avoid this altogether is to use the demeaned returns $\widetilde{R}_i$ instead of R_i, where $\widetilde{R}_i = R_i - R_m$, and the "market index" return R_m is defined by Eq. (469).[171] Then $\eta_i = \text{sign}(\widetilde{R}_i)$ are no longer skewed and dollar-neutrality can be achieved as above.[172]

11 Structured Assets

11.1 Generalities: Collateralized Debt Obligations (CDOs)

A CDO is an asset-backed security (ABS) consisting of a basket of assets such as bonds, credit default swaps, etc. It is divided into multiple tranches, which consist of assets with different credit ratings and interest rates. Each tranche has an attachment point a and a detachment point d. E.g., a 3-8% tranche (for which $a = 3\%$ and $d = 8\%$) means that it begins to lose value when the underlying portfolio loss exceeds 3%; and when the underlying portfolio loss exceeds 8%, the tranche value is completely wiped out.[173] A buyer (long position) of a CDO tranche is a protection seller: in return for receiving periodic premium payments, in the

[171] I.e., in this case the momentum, winners and losers are defined w.r.t. the market index, and the so-defined winners are bought, while the losers are sold.

[172] Further, instead of using cumulative returns R_i, one can use exponential moving averages (to suppress past contributions – see Section 3), the Hodrick-Prescott filter (to remove the noise and identify the trend – see Section 8), the Kalman filter (see, e.g., [Babbs and Nowman, 1999], [Benhamou, 2016], [Bruder *et al*, 2013], [DeMoura, Pizzinga and Zubelli, 2016], [Elliott, Van Der Hoek and Malcolm, 2005], [Engle and Watson, 1987], [Harvey, 1984], [Harvey, 1990], [Hatemi-J, and Roca, 2006], [Kalman, 1960], [Lautier and Galli, 2004], [Levine and Pedersen, 2016], [Martinelli and Rhoads, 2010], [Vidyamurthy, 2004]), or some other time-series filters.

[173] Examples of tranches are (in the decreasing order of default risk and periodic premium payment rate): equity 0-3% tranche; junior mezzanine 3-7% tranche; senior mezzanine 7-10% tranche; senior 10-15% tranche; and super senior 15-30% tranche.

event of a default, the buyer has the obligation to cover the default up to the size of the tranche. A seller (short position) of a CDO tranche is a protection buyer: in return for making periodic premium payments, the seller receives a payment in the event of a default. Synthetic CDOs are "synthesized" through credit derivatives such as CDS (credit default swaps – see Subsection 5.14) on a pool of reference entities (e.g., bonds, loans, names of companies or countries). Reference pools for exchange-traded single-tranche CDOs are CDS indexes such as CDX and iTraxx.[174]

Let t_i, $i = 1, \dots, n$, denote the times at which the periodic premium payments are made.[175] Let $H(t)$ denote the set of possible defaults ℓ_α, $\alpha = 1, \dots, K$, that can occur by time t, and let $p_\alpha(t)$ denote the corresponding probabilities (which are model-dependent). Here ℓ_α are the dollar amounts of the defaults.[176] The expected loss $L(t)$ can be computed as

$$L(t) = \sum_{\alpha=1}^{K} p_\alpha(t)\ \max(\min(\ell_\alpha, L_d) - L_a, 0) \tag{481}$$

where $L_a = a\ M_{CDO}$, $L_d = d\ M_{CDO}$, and M_{CDO} is the CDO notional in dollars.[177] From the long tranche investor's perspective, the mark-to-market (MTM) value of the tranche, call it $\mathcal{M}$, is given by

$$\mathcal{M} = P - C \tag{482}$$

$$P = S\ \sum_{i=1}^{n} D_i\ \Delta_i\,[M_{tr} - L(t_i)] \tag{483}$$

$$C = \sum_{i=1}^{n} D_i\,[L(t_i) - L(t_{i-1})] \tag{484}$$

Here: P is the premium leg; C is the contingent (default) leg; S is the spread; $\Delta_i = t_i - t_{i-1}$; D_i is the risk-free discount factor for the payment date t_i; and

[174] For some literature on CDOs and related topics, see, e.g., [Altman *et al*, 2005], [Amato and Gyntelberg, 2005], [Amato and Remolona, 2003], [Andersen and Sidenius, 2005], [Andersen, Sidenius and Basu, 2003], [Belkin, Suchover and Forest, 1998], [Bielecki, Brigo and Patras, 2011], [Bol, Rachev and Würth, 2009], [Boscher and Ward, 2002], [Cousin and Laurent, 2012], [Das, 2005], [Davis and Lo, 2001], [Ding and Sherris, 2011], [Douglas, 2007], [Duffie, 2004], [Duffie and Gârleanu, 2001], [Duffie and Huang, 1996], [Duffie and Singleton, 1997a], [Duffie and Singleton, 1997b], [Fabozzi, 2006a], [Finger, 1999], [Frey, McNeil and Nyfeler, 2001], [Gibson, 2004], [Goodman, 2002], [Goodman and Lucas, 2002], [Houdain and Guegan, 2006], [Hull and White, 2006], [Hull and White, 2010], [Jarrow, Lando and Turnbull, 1997], [Jarrow and Turnbull, 1995], [Jobst, 2005], [Jobst, 2006a], [Jobst, 2006b], [Jobst, 2006c], [Jobst, 2007], [Laurent and Gregory, 2005], [Li, 2000], [Lucas, Goodman and Fabozzi, 2006], [Meissner, 2008], [Packer and Zhu, 2005], [Prince, 2005], [Schmidt and Ward, 2002], [Schönbucher, 2003], [Tavakoli, 1998], [Vasicek, 2015].

[175] For simplicity, we can also assume that any default payments are also made at those times.

[176] If the notional amount of the defaulted credit labeled by α is M_α, then $\ell_\alpha = M_\alpha(1 - R_\alpha)$, where R_α is the recovery rate (which may be nonzero) of said credit.

[177] Recall that the attachment a and the detachment d are measured in %.

$M_{tr} = L_d - L_a$ is the tranche notional. (Also, t is measured in years, t_0 is the initial time, and $L(t_0) = 0$). Setting the MTM $\mathcal{M} = 0$ fixes the value of the spread $S = S_*$.

We can further define the "risky duration" $\mathcal{D}$ of the tranche as the first derivative of the MTM w.r.t. the spread:

$$\mathcal{M}(S) = (S - S_*) \sum_{i=1}^{n} D_i \, \Delta_i \, [M_{tr} - L(t_i)] \tag{485}$$

$$\mathcal{D} = \partial \mathcal{M} / \partial S = \sum_{i=1}^{n} D_i \, \Delta_i \, [M_{tr} - L(t_i)] \tag{486}$$

The risky duration $\mathcal{D}_{ix}$ can also be defined in a similar fashion for a CDS index.

11.2 Strategy: Carry, equity tranche – index hedging

This strategy amounts to buying the equity (lowest quality) tranche and Delta-hedging it by selling the index. The Delta (i.e., the hedge ratio) is given by[178]

$$\Delta_{ix} = \frac{\mathcal{D}}{\mathcal{D}_{ix}} \tag{487}$$

The premiums received from the equity tranche are higher than the premiums paid on the short index position. The risk is the exposure to equity tranche credit events.

11.3 Strategy: Carry, senior/mezzanine – index hedging

This strategy amounts to *selling* a high quality tranche (e.g., senior/mezzanine) and Delta-hedging the position by *buying* the index.[179] The Delta is given by Eq. (487).

11.4 Strategy: Carry – tranche hedging

This strategy amounts to buying a low quality tranche and Delta-hedging the position by selling a high quality tranche. The hedge ratio is given by:

$$\Delta_{high} = \frac{\mathcal{D}_{low}}{\mathcal{D}_{high}} \tag{488}$$

Here $\mathcal{D}_{low}$ and $\mathcal{D}_{high}$ are the risky durations of the low and high quality tranches.

[178] For some literature on CDO tranche hedging and related topics, see, e.g., [Arnsdorf and Halperin, 2007], [Bielecki, Jeanblanc and Rutkowski, 2007], [Bielecki, Vidozzi and Vidozzi, 2008], [Carmona and Crépey, 2010], [Cont and Minca, 2013], [Frey and Backhaus, 2008], [Frey and Backhaus, 2010], [Giesecke and Weber, 2006], [Herbertsson, 2008], [Houdain and Guegan, 2006], [Laurent, Cousin and Fermanian, 2011], [Walker, 2008].

[179] The premiums received from the index are higher than the premiums paid on the short tranche position. So, this trade is "opposite" to the long equity tranche trade hedged with the index.

11.5 Strategy: Carry – CDS hedging

This strategy amounts to buying a low quality tranche and Delta-hedging the position by selling a single-name CDS with lower premium payments than the long tranche (instead of the index or a higher quality tranche). The hedge ratio is given by Eq. (487) with $\mathcal{D}_{ix}$ replaced by the risky duration $\mathcal{D}_{CDS}$ of the CDS:

$$\Delta_{CDS} = \frac{\mathcal{D}}{\mathcal{D}_{CDS}} \tag{489}$$

11.6 Strategy: CDOs – curve trades

As in the case of bonds (see Subsection 5.13), a flattener (steepener) curve trade involves a simultaneous sale (purchase) of a short-term tranche and a purchase (sale) of a long-term tranche. Put differently, with a flattener (steepener), the trader is buying (selling) short-term protection and selling (buying) long-term protection, i.e., the trader expects the spread curve to flatten (steepen), whereby the spread between the long-term and short-term tranches decreases (increases). The carry of the curve trade over the period from time t to time $t + \Delta t$ can be defined as follows

$$C(t, t+\Delta t) = (M_{long}\ S_{long} - M_{short}\ S_{short})\,\Delta t \tag{490}$$

where M_{long} and M_{short} are the long and short tranche notionals, and S_{long} and S_{short} are the corresponding spreads. The trade can be structured to be dollar-neutral (i.e., notional-neutral, $M_{long} = M_{short}$),[180] risky-duration-neutral ($\mathcal{D}_{long} = \mathcal{D}_{short}$, see Eq. (486)), carry-neutral ($M_{long}S_{long} = M_{short}S_{short}$), etc.[181] The P&L of the strategy is given by ($\mathcal{M}_{long}$ and $\mathcal{M}_{short}$ are the long and short tranche MTMs, see Eq. (485)):

$$\text{P\&L} = \mathcal{M}_{long} - \mathcal{M}_{short} \tag{491}$$

11.7 Strategy: Mortgage-backed security (MBS) trading

This strategy amounts to buying MBS passthroughs[182] and duration-hedging their interest rate exposure with interest rate swaps. Thus, the main risk of a passthrough MBS is the prepayment risk, whereby homeowners have an option to prepay their mortgages. Homeowners refinance their mortgages as the interest rates drop, which results in negative convexity in the MBS price as a function of the interest rates

[180] In this case, for an upward-sloping curve, a flattener (steepener) has positive (negative) carry as $S_{long} > S_{short}$ ($S_{long} < S_{short}$).

[181] For some literature on curve trades and related topics, see, e.g., [Bobey, 2010], [Burtshell, Gregory and Laurent, 2009)], [Choroś-Tomczyk, Härdle and Okhrin, 2016], [Crabbe and Fabozzi, 2002], [Detlefsen and Härdle, 2013], [Hagenstein, Mertz and Seifert, 2004], [Hamerle, Igl and Plank, 2012], [Hull and White, 2004], [Kakodkar *et al*, 2006], [Koopman, Lucas and Schwaab, 2012], [Lin and Shyy, 2008], [Rajan, McDermott and Roy, 2007].

[182] An MBS is an asset backed by a pool of mortgages. In a passthrough MBS, which is the most common MBS type, cash flows are passed from debtors to investors through an intermediary.

(e.g., the 5-year swap rate). The hedge ratios are model-dependent and a variety of prepayment models can be constructed. Alternatively one can follow a nonparametric approach whereby using historical data one estimates the first derivative of the passthrough MBS price P w.r.t. the 5-year swap rate R with the constraint that P is a non-increasing function of R (see, e.g., [Duarte, Longstaff and Yu, 2006]),[183] employing, e.g., a constrained regression (see, e.g., [Aït-Sahalia and Duarte, 2003]).

12 Convertibles

12.1 Strategy: Convertible arbitrage

A convertible bond is a hybrid security with an embedded option to convert the bond (a fixed-income instrument) to a preset number (knows as the conversion ratio) of the issuer's stock (an equity instrument) when, e.g., the stock price reaches a preset level (known as the conversion price). Empirically, convertibles at the issuance tend to be undervalued relative to their "fair" value.[184] This gives rise to arbitrage opportunities. A convertible arbitrage strategy amounts to buying a convertible bond and simultaneously shorting h units of the underlying stock, where the hedge ratio is given by

$$h = \Delta \times C \quad (492)$$

$$\Delta = \partial V / \partial S \quad (493)$$

Here: C is the conversion ratio; V is the value of the conversion option (which is model-dependent); S is the underlying stock price; and Δ is the (model-dependent)

[183] For some additional pertinent literature, see, e.g., [Ambrose, LaCour-Little and Sanders, 2004], [Biby, Modukuri and Hargrave, 2001], [Bielecki, Brigo and Patras, 2011], [Boudoukh *et al*, 1997], [Brazil, 1988], [Brennan and Schwartz, 1985], [Carron and Hogan, 1988], [Chinloy, 1989], [Davidson, Herskovitz and Van Drunen, 1988], [Dechario *et al*, 2010], [Downing, Jaffee and Wallace, 2009], [Dunn and McConnell, 1981a], [Dunn and McConnell, 1981b], [Dynkin *et al*, 2001], [Fabozzi, 2006b], [Gabaix, Krishnamurthy and Vigneron, 2007], [Glaeser and Kallal, 1997], [Hu, 2001], [Longstaff, 2005], [Kau *et al*, 1995], [McConnell and Buser, 2011], [McKenzie, 2002], [Nothaft, Lekkas and Wang, 1995], [Passmore, Sherlund and Burgess, 2005], [Richard and Roll, 1989], [Schultz, 2016], [Schwartz and Torous, 1989], [Schwartz and Torous, 1992], [Stanton, 1995], [Thibodeau and Giliberto, 1989], [Vickery and Wright, 2010].

[184] For some literature on convertible bonds and related topics, see, e.g., [Agarwal *et al*, 2011], [Ammann, Kind and Seiz, 2010], [Ammann, Kind and Wilde, 2003], [Batta, Chacko and Dharan, 2010], [Brennan and Schwartz, 1988], [Brown *et al*, 2012], [Calamos, 2003], [Chan and Chen, 2007], [Choi *et al*, 2010], [Choi, Getmansky and Tookes, 2009], [De Jong, Dutordoir and Verwijmeren, 2011], [Duca *et al*, 2012], [Dutordoir *et al*, 2014], [Grundy and Verwijmeren, 2016], [Henderson, 2005], [Henderson and Tookes, 2012], [Ingersoll, 1977], [Kang and Lee, 1996], [King, 1986], [King and Mauer, 2014], [Korkeamaki and Michael, 2013], [Lewis, Rogalski and Seward, 1999], [Lewis and Verwijmeren, 2011], [Loncarski, ter Horst and Veld, 2006], [Loncarski, ter Horst and Veld, 2009], [Mayers, 1998], [Ryabkov, 2015], [Stein, 1992], [Tsiveriotis and Fernandes, 1998], [van Marle and Verwijmeren, 2017], [Zabolotnyuk, Jones and Veld, 2010].

Delta of the conversion option.[185] Typically, the position is held for 6-12 months starting at the issuance date of the convertible and the hedge ratio is updated daily.

12.2 Strategy: Convertible option-adjusted spread

This strategy amounts to simultaneously buying and selling two different convertible bonds of the same issuer. The long position is in a bond with a higher option-adjusted spread (OAS), and the short position is in a bond with a lower OAS (see, e.g., [Calamos, 2003]). Then the trade is profitable if these two spreads converge.

The OAS can be calculated as follows (see, e.g., [Hull, 2012]).[186] A straightforward (but not the only)[187] way to compute the price P_C of the convertible bond is to assume that

$$P_C = P_B + V \tag{494}$$

where P_B is the price of the straight bond (without the embedded option), and V is the value of the conversion option, which is a call option. P_B is computed via the standard discounting of the future cash flows of the bond. On the other hand, V depends on the risk-free interest rate curve. At the initial iteration, V is computed (using a pricing model for the call option) assuming the zero-coupon government Treasury curve as the risk-free interest rate curve. This initial iteration $V^{(0)}$ may not coincide with $P_C^{mkt} - P_B$, where P_C^{mkt} is the *market price* of the convertible bond. Then one iteratively (e.g., using the bisection method) *parallel-shifts* the input Treasury curve until V computed using the so-shifted curve is such that $V = P_C^{mkt} - P_B$. The curve parallel shift obtained via this iterative procedure is the OAS.

13 Tax Arbitrage

13.1 Strategy: Municipal bond tax arbitrage

This strategy is one of the most common and simple forms of tax arbitrage. It amounts to borrowing money and buying tax-exempt municipal bonds.[188] The strat-

[185] The Delta itself changes with the stock price S. To account for this, the option Gamma can be used as in Subsection 7.4.1 (Gamma hedging).

[186] For some additional literature related to OAS (mostly focused on applications to MBS), see, e.g., [Boyarchenko, Fuster and Lucca, 2014], [Brazil, 1988], [Brown, 1999], [Cerrato and Djennad, 2008], [Dong *et al*, 2009], [Hayre, 1990], [Huang and Kong, 2003], [Levin and Davidson, 2005], [Liu and Xu, 1998], [Stroebel and Taylor 2012], [Windas, 2007].

[187] For some literature on convertible bond pricing, see, e.g., [Ayache, Forsyth and Vetzal, 2003], [Batten, Khaw and Young, 2014], [Brennan and Schwartz, 1977], [Finnerty and Tu, 2017], [Ingersoll, 1977], [Kang and Lee, 1996], [King, 1986], [Kwok, 2014], [McConnell and Schwartz, 1986], [Milanov *et al*, 2013], [Park, Jung and Lee, 2018], [Sörensson, 1993], [Tsiveriotis and Fernandes, 1998], [Xiao, 2013], [Zabolotnyuk, Jones and Veld, 2010].

[188] For some literature on municipal bond tax arbitrage and related topics, see, e.g., [Ang *et al*, 2017], [Buser and Hess, 1986], [Chalmers, 1998], [Erickson, Goolsbee and Maydew, 2003], [Heaton, 1988], [Kochin and Parks, 1988], [Longstaff, 2011], [Miller, 1977], [Poterba, 1986], [Poterba, 1989],

egy return is given by

$$R = r_{long} - r_{short}\,(1 - \tau) \tag{495}$$

Here: r_{long} is the interest rate of the bought municipal bonds, r_{short} is the interest rate of the loan, and τ is the corporate tax rate. This strategy is attractive to companies in jurisdictions where tax rules allow them to buy tax-exempt municipal bonds and deduct interest expenses from their taxable income (a.k.a. "tax shield").

13.2 Strategy: Cross-border tax arbitrage

The U.S. double-taxes corporate income. The corporate income is first taxed at the corporate level. Then, it is taxed again when dividends are received by the shareholders. In some other countries the taxation systems are designed to relieve the tax burden, e.g., by not taxing dividends (as, e.g., in Singapore), or by giving shareholders tax credits attached to dividend payments (as, e.g., in Australia). In the case where this "dividend imputation" corporate tax system gives the full tax credit to shareholders, it can be schematically described as follows (see, e.g., [McDonald, 2001]):[189]

$$\begin{cases} \text{Corporate tax rate} = \tau_c \\ \text{Cash dividend paid} = D \\ \text{Dividend tax credit} = C = D\,\frac{\tau_c}{1-\tau_c} \\ \text{Taxable income} = I_t = D + C = \frac{D}{1-\tau_c} \\ \text{Personal tax rate} = \tau_p \\ \text{Personal income tax} = T = I_t\,\tau_p \\ \text{Dividend income after credit and tax} = I = D + C - T = D\,\frac{1-\tau_p}{1-\tau_c} \end{cases} \tag{496}$$

So, if the corporate income is P and the corporation pays all its income after taxes as dividends, then $D = P\,(1-\tau_c)$ and $I = P\,(1-\tau_p)$, so there is no double-taxation.[190]

While in countries with imputation systems domestic investors enjoy tax credits, generally foreign investors do not. If there were no tax credits, the price drop between cum-dividend and ex-dividend[191] is expected to reflect the dividend. In the presence of tax credits, the drop is expected to be higher: if it fully reflects the tax credit, then it is $D\,(1+\kappa)$, where κ is the tax credit rate. (In the above nomenclature, $1 + \kappa = 1/(1+\tau_c)$.) So, a foreign investor is effectively penalized for

[Skelton, 1983], [Trzcinka, 1982], [Yawitz, Maloney and Ederington, 1985].

[189] However, there can be limitations on the tax credit and other subtleties present depending on the jurisdiction, various circumstances, etc.

[190] In contrast, in the double-taxation system we would instead have: $D = P\,(1-\tau_c)$, $I_t = D$, $T = I_t\,\tau_p$, $I = I_t - T = P\,(1-\tau_c)\,(1-\tau_p)$.

[191] Cum-dividend means the stock buyer is entitled to receive a dividend that has been declared but not paid. Ex-dividend means the stock seller is entitled to the dividend, not the buyer.

holding the stock. To avoid this, the foreign investor can sell the stock cum-dividend and buy it back ex-dividend.[192] Alternatively, the foreign investor can loan the stock to a domestic investor cum-dividend and receive the stock back ex-dividend along with (some preset portion of) the tax credit – assuming no restrictions on such cross-border tax arbitrage. A swap agreement would also achieve the same result.[193]

13.2.1 Strategy: Cross-border tax arbitrage with options

Absent a tax credit, there is a theoretical upper bound on the value of an American put option (see, e.g., [Hull, 2012]):

$$V_{put}(K,T) \leq V_{call}(K,T) - S_0 + K + D \qquad (497)$$

Here: V_{put} (V_{call}) is the price of the put (call) option at time $t = 0$; K is the strike price; S_0 is the stock price at $t = 0$; T is the time to maturity; and D is the present value of the dividends during the life of the option. Put options are optimally exercised ex-dividend. Therefore, in the presence of a tax credit, it is expected that put prices should reflect the tax credit, i.e., they should be higher than in the absence of the tax credit (see, e.g., [McDonald, 2001]). So the foreign investor can sell the stock cum-dividend (at price S_0) and write a deep ITM put option, whose value close to expiration approximately is (here κ is the tax credit rate defined above)

$$V_{put}(K,T) = K - [S_0 - D\,(1+\kappa)] \qquad (498)$$

The P&L, once the put is exercised ex-dividend at the strike price K, is the same as with the stock loan/swap strategy discussed above:

$$\text{P\&L} = S_0 + V_{put}(K,T) - K = D\,(1+\kappa) \qquad (499)$$

14 Miscellaneous Assets

14.1 Strategy: Inflation hedging – inflation swaps

This strategy amounts to buying (selling) inflation swaps in order to exchange a fixed (floating) rate of inflation for a floating (fixed) rate. Inflation swaps conceptually are similar to interest rate swaps (see Subsection 5.1.4). A buyer (seller) of an inflation swap is long (short) the inflation and receives the floating (fixed) rate. The buyer has a positive return if the inflation exceeds the expected inflation (i.e., the swap

[192] Assuming transaction costs are not prohibitively high.

[193] For some literature on cross-border tax arbitrage and related topics, see, e.g., [Allen and Michaely, 1995], [Amihud and Murgia, 1997], [Bellamy, 1994], [Booth, 1987], [Booth and Johnston, 1984], [Brown and Clarke, 1993], [Bundgaard, 2013], [Callaghan and Barry, 2003], [Christoffersen *et al*, 2005], [Christoffersen *et al*, 2003], [Eun and Sabherwal, 2003], [Green and Rydqvist, 1999], [Harris, Hubbard and Kemsley, 2001], [Lakonishok and Vermaelen, 1986], [Lasfer, 1995], [Lessambo, 2016], [McDonald, 2001], [Monkhouse, 1993], [Shaviro, 2002], [Wells, 2016], [Wood, 1997].

fixed rate, a.k.a. the "breakeven rate"). The fixed rate typically is calculated as the interest rate spread between the Treasury notes/bonds (as applicable) and Treasury Inflation-Protected Securities (TIPS) with the same maturity as that of the swap. The floating rate usually is based on an inflation index such as the Consumer Price Index (CPI). The most common type of inflation swap is the zero-coupon inflation swap (ZC), which has only one cash flow at maturity T (measured in years). This cash flow is the difference between the fixed rate cash flow C_{fixed} and the floating rate cash flow $C_{floating}$. These cash flows, per \$1 notational, are given by:

$$C_{fixed} = (1 + K)^T - 1 \tag{500}$$
$$C_{floating} = I(T)/I(0) - 1 \tag{501}$$

Here: K is the fixed rate; and $I(t)$ is the CPI value at time t ($t = 0$ is the time at which the swap contract is entered into). Another type of inflation swaps is the year-on-year inflation swap (YoY), which references annual inflation (as opposed to the cumulative inflation referenced by the zero-coupon swap). Thus, assuming for simplicity annual payments, we have (here $t = 1, \dots, T$ is measured in years):[194]

$$C_{fixed}(t) = K \tag{502}$$
$$C_{floating}(t) = I(t)/I(t-1) - 1 \tag{503}$$

14.2 Strategy: TIPS-Treasury arbitrage

This strategy is based on the empirical observation that Treasury bonds tend to be overvalued relative to TIPS[195] almost all the time (see, e.g., [Campbell, Shiller and Viceira, 2009], [Driessen, Nijman and Simon, 2017], [Fleckenstein, 2012], [Haubrich,

[194] For some literature on inflation swaps and related topics, see, e.g., [Belgrade and Benhamou, 2004], [Belgrade, Benhamou and Koehler, 2004], [Bouzoubaa and Osseiran, 2010], [Christensen, Lopez and Rudebusch, 2010], [Deacon, Derry and Mirfendereski, 2004], [Fleming and Sporn, 2013], [Haubrich, Pennacchi and Ritchken, 2012], [Hinnerich, 2008], [Jarrow and Yildirim, 2003], [Kenyon, 2008], [Lioui and Poncet, 2005], [Martellini, Milhau and Tarelli, 2015], [Mercurio, 2005], [Mercurio and Moreni, 2006], [Mercurio and Moreni, 2009], [Mercurio and Yildirim, 2008].

[195] TIPS pay semiannual fixed coupons at a fixed rate, but the coupon payments (and principal) are adjusted based on inflation. For some literature on TIPS, inflation-indexed products and related topics, see, e.g., [Adrian and Wu, 2010], [Ang, Bekaert and Wei, 2008], [Bardong and Lehnert, 2004], [Barnes *et al*, 2010], [Barr and Campbell, 1997], [Bekaert and Wang, 2010], [Buraschi and Jiltsov, 2005], [Campbell, Sunderam and Viceira, 2017], [Chen, Liu and Cheng, 2010], [Chernov and Mueller, 2012], [Christensen and Gillan, 2012], [D'Amico, Kim and Wei, 2018], [Deacon, Derry and Mirfendereski, 2004], [Dudley, Roush and Steinberg, 2009], [Evans, 1998], [Fleckenstein, Longstaff and Lustig, 2017], [Fleming and Krishnan, 2012], [Grishchenko and Huang, 2013], [Grishchenko, Vanden and Zhang, 2016], [Gürkaynak, Sack and Wright, 2010], [Hördahl and Tristani, 2012], [Hördahl and Tristani, 2014], [Hunter and Simon, 2005], [Jacoby and Shiller, 2008], [Joyce, Lildholdt and Sorensen, 2010], [Kandel, Ofer and Sarig, 1996], [Kitsul and Wright, 2013], [Kozicki and Tinsley, 2012], [Mehra, 2002], [Pennacchi, 1991], [Pflueger and Viceira, 2011], [Remolona, Wickens and Gong, 1998], [Roll, 1996], [Roll, 2004], [Sack and Elsasser, 2004], [Seppälä, 2004], [Shen, 2006], [Shen and Corning, 2001], [Woodward, 1990], [Yared and Veronesi, 1999].

Pennacchi and Ritchken, 2012]). The strategy amounts to selling a Treasury bond (whose price is $P_{Treasury}$, fixed coupon rate is $r_{Treasury}$, and maturity is T) and offsetting this short position with a synthetic portfolio, which precisely replicates the Treasury bond coupon and principal payments, but costs less than the Treasury bond. This synthetic portfolio is constructed by buying TIPS (whose price is P_{TIPS} and maturity T is the same as that of the Treasury bond) with a fixed coupon rate r and n coupon payments at times t_i, $i = 1, \dots, n$ (with $t_n = T$), and simultaneously selling n zero-coupon inflation swaps with maturities t_i, the fixed rate K, and the notionals $N_i = r + \delta_{t_i,T}$ per \$1 of the TIPS principal. The cash flows (per \$1 notional) at $t = t_i$ are given by (as above, $I(t)$ is the CPI value at time t; also, time is measured in the units of the (typically, semiannual) compounding periods):

$$C_{TIPS}(t_i) = N_i \ I(t_i)/I(0) \tag{504}$$
$$C_{swap}(t_i) = N_i \left[(1 + K)^{t_i} - I(t_i)/I(0)\right] \tag{505}$$
$$C_{total}(t_i) = C_{swap}(t_i) + C_{TIPS}(t_i) = N_i \, (1 + K)^{t_i} \tag{506}$$

So, the synthetic portfolio converts the indexed payments from TIPS into fixed payments with the effective coupon rates $r_{eff}(t_i) = r\,(1 + K)^{t_i}$. These synthetic coupon payments almost replicate the Treasury bond coupons $r_{Treasury}$. The exact matching involves small long or short positions in STRIPS[196], which are given by (see, e.g., [Fleckenstein, Longstaff and Lustig, 2013] for details)

$$S(t_i) = D(t_i) \left\{[r_{Treasury} - r_{eff}(t_i)] + \delta_{t_i,T}\left[1 - (1 + K)^{t_i}\right]\right\} \tag{507}$$

where $D(\tau)$ is the value of the STRIPS with maturity τ at time $t = 0$ (i.e., $D(\tau)$ is a discount factor). In Eq. (507) the second term in the curly brackets (which is proportional to $\delta_{t_i,T}$ and is nonzero only for $i = n$, i.e., at maturity T) is included as we must also match the principals at maturity. Note that the STRIPS positions are established at $t = 0$. The net cash flow $C(0)$ at $t = 0$ is given by (note that the net cash flows at $t > 0$ are all null by replication)

$$C(0) = P_{Treasury} - P_{TIPS} - \sum_{i=1}^{n} S(t_i) \tag{508}$$

Empirically $C(0)$ tends to be positive (even after transaction costs). Hence arbitrage.

14.3 Strategy: Weather risk – demand hedging

Various businesses and sectors of the economy can be affected by weather conditions, both directly and indirectly. Weather risk is hedged using weather derivatives. There are no "tradable" weather indexes, so various synthetic indexes have been created.

[196] STRIPS = "Separate Trading of Registered Interest and Principal of Securities". Essentially, STRIPS are zero-coupon discount bonds.

The most common ones are based on temperature. The cooling-degree-days (CDD) and heating-degree-days (HDD) measure extreme high temperatures and extreme low temperatures, respectively:[197]

$$I_{CDD} = \sum_{i=1}^{n} \max(0, T_i - T_{base}) \quad (509)$$

$$I_{HDD} = \sum_{i=1}^{n} \max(0, T_{base} - T_i) \quad (510)$$

$$T_i = \frac{T_i^{min} + T_i^{max}}{2} \quad (511)$$

Here: $i = 1, \dots, n$ labels days; n is the life of the contract (a week, a month or a season) measured in days; T_i^{min} and T_i^{max} are the minimum and maximum temperatures recorded on the day labeled by i; and $T_{base} = 65°\text{F}$. Then, the demand risk for heating days can, e.g., be hedged by a short futures position or a long put option position with the hedge ratios given by (here (Cov) Var is serial (co)variance):

$$h_{futures}^{HDD} = \text{Cov}(q_w, I_{HDD})/\text{Var}(I_{HDD}) \quad (512)$$

$$h_{put}^{HDD} = -\text{Cov}\left(q_w, \max(K - I_{HDD}, 0)\right)/\text{Var}\left(\max(K - I_{HDD}, 0)\right) \quad (513)$$

Here: q_w is the portion of the demand affected by weather conditions (as there might be other, exogenous, non-weather-related components to the demand); and K is the strike price. Similarly, the demand risk for cooling days can, e.g., be hedged by a long futures position or a long call option position with the hedge ratios given by:

$$h_{futures}^{CDD} = \text{Cov}(q_w, I_{CDD})/\text{Var}(I_{CDD}) \quad (514)$$

$$h_{call}^{CDD} = \text{Cov}\left(q_w, \max(I_{CDD} - K, 0)\right)/\text{Var}\left(\max(I_{CDD} - K, 0)\right) \quad (515)$$

[197] For some literature on weather derivatives, weather indexes and related topics, see, e.g., [Alaton, Djehiche and Stillberger, 2010], [Barrieu and El Karoui, 2002], [Barrieu and Scaillet, 2010], [Benth, 2003], [Benth and Saltyte-Benth, 2005], [Benth and Saltyte-Benth, 2007], [Benth, Saltyte-Benth and Koekebakker, 2007], [Bloesch and Gourio, 2015], [Brockett *et al*, 2010], [Brockett, Wang and Yang, 2005], [Brody, Syroka and Zervos, 2002], [Campbell and Diebold, 2005], [Cao and Wei, 2000], [Cao and Wei, 2004], [Cartea and Figueroa, 2005], [Chaumont, Imkeller and Müller, 2006], [Chen, Roberts and Thraen, 2006], [Corbally and Dang, 2002], [Davis, 2001], [Dischel, 1998a], [Dischel, 1998b], [Dischel, 1999], [Dorfleitner and Wimmer, 2010], [Dornier and Queruel, 2000], [Ederington, 1979], [Geman, 1998], [Geman and Leonardi, 2005], [Ghiulnara and Viegas, 2010], [Golden, Wang and Yang, 2007], [Göncü, 2012], [Hamisultane, 2009], [Hanley, 1999], [Härdle and López Cabrera, 2011], [Huang, Shiu and Lin, 2008], [Huault and Rainelli-Weis, 2011], [Hunter, 1999], [Jain and Baile, 2000], [Jewson, 2004a], [Jewson, 2004b], [Jewson, Brix and Ziehmann, 2005], [Jewson and Caballero, 2003], [Lazo *et al*, 2011], [Lee and Oren, 2009], [Leggio and Lien, 2002], [Mraoua, 2007], [Müller and Grandi, 2000], [Oetomo and Stevenson, 2005], [Parnaudeau and Bertrand, 2018], [Perez-Gonzalez and Yun, 2010], [Richards, Manfredo and Sanders, 2004], [Saltyte-Benth and Benth, 2012], [Schiller, Seidler and Wimmer, 2010], [Svec and Stevenson, 2007], [Swishchuk and Cui, 2013], [Tang and Jang, 2011], [Thornes, 2006], [Vedenov and Barnett, 2004], [Wilson, 2016], [Woodard and Garcia, 2008], [Yang, Brockett and Wen, 2009], [Zapranis and Alexandridis, 2008], [Zapranis and Alexandridis, 2009], [Zeng, 2000].

14.4 Strategy: Energy – spark spread

The spark spread is the difference between the wholesale price of electricity and the price of natural gas required to produce it.[198] A spark spread can be built by, e.g., taking a short position in electricity futures and a long position in the corresponding number of fuel futures. Such positions are used by electricity producers to hedge against changes in the electricity price or in the cost of fuel, as well as by traders or speculators who want to make a bet on a power plant. The number of fuel futures is determined by the so-called *heat rate* H, which measures the efficiency with which the plant converts fuel into electricity:

$$H = Q_F/Q_E \tag{516}$$

Here: Q_F is the amount of fuel used to produce the amount of electricity Q_E; Q_F is measured in MMBtu; Btu = British thermal unit, which is approximately 1,055 Joules; MBtu = 1,000 Btu; MMBtu = 1,000,000 Btu; Q_E is measured in Mwh = Megawatt hour; the heat rate H is measured in MMBtu/Mwh. The spark spread is measured in \$/Mwh. So, if the price of electricity is P_E (measured in \$/Mwh) and the price of fuel is P_F (measured in \$/MMBtu), then the spark spread is given by

$$S = P_E - H\ P_F \tag{517}$$

The hedge ratio for the futures is affected by the available futures contract sizes. Thus, an electricity futures contract is $F_E = 736$ Mwh, and a gas futures contract is $F_F = 10,000$ MMBtu. So, the hedge ratio is given by

$$h = H\ F_E/F_F \tag{518}$$

which generally is not a whole number. Therefore, it is (approximately, within the desired precision) represented as a ratio $h \approx N_F/N_E$ with the lowest possible denominator N_E, where N_F and N_E are whole numbers. Then the hedge consists of buying N_F gas futures contracts for every N_E sold electricity futures contracts.

15 Distressed Assets

15.1 Strategy: Buying and holding distressed debt

Distressed securities are those whose issuers are undergoing financial/operational distress, default or bankruptcy. One definition of distressed debt is if the spread

[198] So, the spark spread measures a gross margin of a gas-fired power plant excluding all other costs for operation, maintenance, capital, etc. Also, if the power plant uses fuel other than natural gas, then the corresponding spread has a different name. For coal it is called "dark spread"; for nuclear power it is called "quark spread"; etc. For some literature on energy spreads, energy hedging and related topics, see, e.g., [Benth and Kettler, 2010], [Benth, Kholodnyi and Laurence, 2014], [Carmona and Durrleman, 2003], [Cassano and Sick, 2013], [Deng, Johnson and Sogomonian, 2001], [Edwards, 2009], [Elias, Wahab and Fang, 2016], [Emery and Liu, 2002], [Fiorenzani, 2006], [Fusaro and James, 2005], [Hsu, 1998], [James, 2003], [Kaminski, 2004], [Li and Kleindorfer, 2009], [Maribu, Galli and Armstrong, 2007], [Martínez and Torró, 2018], [Wang and Min, 2013].

between the yields of Treasury bonds and those of the issuer is greater than some preset number, e.g., 1,000 basis points (see, e.g., [Harner, 2008]). A common and simple distressed debt passive trading strategy amounts to buying debt of a distressed company at a steep discount,[199] expecting (hoping) that the company will repay its debt. Typically, a distressed debt portfolio is diversified across industries, entities and debt seniority level. It is anticipated that only a small fraction of the held assets will have positive returns, but those that do, will provide high rates of return (see, e.g., [Greenhaus, 1991]). There are two broad categories of passive distressed debt strategies (see, e.g., [Altman and Hotchkiss, 2006]). First, using various models (see Subsection 15.3) one can attempt to predict whether a company will declare bankruptcy. Second, some strategies focus on assets of companies in default or bankruptcy, a successful reorganization being the driver of returns. Typically, positions are established at key dates, such as at the end of the default month or at the end of the bankruptcy-filing month, with the view of exploiting overreaction in the distressed debt market (see, e.g., [Eberhart and Sweeney, 1992], [Gilson, 1995]).

15.2 Strategy: Active distressed investing

This strategy amounts to buying distressed assets with the view (unlike the passive strategy discussed above) to acquire some degree of control of the management and direction of the company. When facing a distress situation, a company has various options in its reorganization process. It can file for bankruptcy protection under Chapter 11 of the U.S. Bankruptcy Code to reorganize. Or it can work directly with its creditors out of Court.[200] Below are some scenarios for active investing.

15.2.1 Strategy: Planning a reorganization

An investor can submit a reorganization plan to Court with an objective to obtain participation in the management of the company, attempt to increase its value and generate profits. Plans by significant debt holders tend to be more competitive.

15.2.2 Strategy: Buying outstanding debt

This strategy amounts to buying outstanding debt of a distressed firm at a discount with the view that, after reorganization, part of this debt will be converted into the firm's equity thereby giving the investor a certain level of control of the company.

[199] For some pertinent literature, see, e.g., [Altman, 1998], [Clark and Weinstein, 1983], [Eberhart, Altman and Aggarwal, 1999], [Friewald, Jankowitsch and Subrahmanyam, 2012], [Gande, Altman and Saunders, 2010], [Gilson, 2010], [Gilson, 2012], [Harner, 2011], [Hotchkiss and Mooradian, 1997], [Jiang, Li and Wang, 2012], [Lhabitant, 2002], [Morse and Shaw, 1988], [Moyer, Martin and Martin, 2012], [Putnam, 1991], [Quintero, 1989], [Reiss and Phelps, 1991], [Volpert, 1991].

[200] For some literature, see, e.g., [Altman and Hotchkiss, 2006], [Chatterjee, Dhillon and Ramírez, 1996], [Gilson, 1995], [Gilson, John and Lang, 1990], [Jostarndt and Sautner, 2010], [Levy, 1991], [Markwardt, Lopez and DeVol, 2016], [Perić, 2015], [Rosenberg, 1992], [Swank and Root, 1995], [Ward and Griepentrog, 1993].

15.2.3 Strategy: Loan-to-own

This strategy amounts to financing (via secured loans) a distressed firm that is not bankrupt with the view that it i) overcomes the distress situation, avoids bankruptcy and increases its equity value, or ii) files for Chapter 11 protection and, upon reorganization, the secured loan is converted into the firm's equity with control rights.

15.3 Strategy: Distress risk puzzle

Some studies suggest that companies more prone to bankruptcy offer higher returns, which is a form of a risk premium (see, e.g., [Chan and Chen, 1991], [Fama and French, 1992], [Fama and French, 1996], [Vassalou and Xing, 2004]). However, more recent studies suggest the opposite, i.e., that such companies do not outperform healthier ones, and that the latter actually offer higher returns. This is the so-called "distress risk puzzle" (see, e.g., [George and Hwang, 2010], [Godfrey and Brooks, 2015], [Griffin and Lemmon, 2002], [Ozdagli, 2010]). So, this strategy amounts to buying the safest companies and selling the riskiest ones. As a proxy, one can use the probability of bankruptcy P_i, $i = 1, \dots, N$ (N is the number of stocks), which can, e.g., be modeled via a logistic regression (see, e.g., [Campbell, Hilscher and Sziglayi, 2008]).[201] A zero-cost portfolio can be constructed by, e.g., selling the stocks in the top decile by P_i, and buying the stocks in the bottom decile. Typically, the portfolio is rebalanced monthly, but annual rebalancing is also possible (with similar returns).

15.3.1 Strategy: Distress risk puzzle – risk management

This strategy is a variation of the distress risk puzzle strategy in Subsection 15.3. Empirical studies suggest that zero-cost healthy-minus-distressed (HMD) strategies tend to have a high time-varying market beta, which turns significantly negative following market downturns (usually associated with increased volatility), which can cause large losses if the market bounces abruptly (see, e.g., [Garlappi and Yan, 2011], [O'Doherty, 2012], [Opp, 2017]). This is similar to what happens in other

[201] For some literature on models for estimating bankruptcy probabilities, explanatory variables and related topics, see, e.g., [Alaminos, del Castillo and Fernández, 2016], [Altman, 1968], [Altman, 1993], [Aretz and Pope, 2013], [Beaver, 1966], [Beaver, McNichols and Rhie, 2005], [Bellovary, Giacomino and Akers, 2007], [Brezigar-Masten and Masten, 2012], [Callejón *et al*, 2013], [Chaudhuri and De, 2011], [Chava and Jarrow, 2004], [Chen *et al*, 2011], [Cultrera and Brédart, 2015], [Dichev, 1998], [Duffie, Saita and Wang, 2007], [DuJardin, 2015], [El Kalak and Hudson, 2016], [Fedorova, Gilenko and Dovzhenko, 2013], [Ferreira, Grammatikos and Michala, 2016], [Gordini, 2014], [Griffin and Lemmon, 2002], [Hensher and Jones, 2007], [Hillegeist *et al*, 2004], [Jo, Han and Lee, 1997], [Jonsson and Fridson, 1996], [Korol, 2013], [Laitinen and Laitinen, 2000], [McKee and Lensberg, 2002], [Min, Lee and Han, 2006], [Mossman *et al*, 1998], [Odom and Sharda, 1990], [Ohlson, 1980], [Philosophov and Philosophov, 2005], [Pindado, Rodrigues and de la Torre, 2008], [Podobnik *et al*, 2010], [Ribeiro *et al*, 2012], [Shin and Lee, 2002], [Shumway, 2001], [Slowinski and Zopounidis, 1995], [Tinoco and Wilson, 2013], [Tsai, Hsu and Yen, 2014], [Wilson and Sharda, 1994], [Woodlock and Dangol, 2014], [Yang, You and Ji, 2011], [Zhou, 2013], [Zmijewski, 1984].

factor-based strategies.[202] To mitigate this, the strategy can be modified as follows (see, e.g., [Eisdorfer and Misirli, 2015]):

$$\text{HMD}_* = \frac{\sigma_{target}}{\widehat{\sigma}}\,\text{HMD} \tag{519}$$

Here: HMD is for the standard HMD strategy in Subsection 15.3; σ_{target} is the level of target volatility (typically, between 10% and 15%, depending on the trader preferences); and $\widehat{\sigma}$ is the estimated realized volatility over the prior year using daily data. So, 100% of the investment is allocated only if $\widehat{\sigma} = \sigma_{target}$, and a lower amount is allocated when $\widehat{\sigma} > \sigma_{target}$. When $\widehat{\sigma} < \sigma_{target}$, the strategy could be leveraged.[203]

16 Real Estate

16.1 Generalities

Real estate, unlike most other financial assets, is tangible. It can be divided into two main groups: commercial (offices, shopping centers, etc.) and residential (houses, apartments, etc.) real estate. There are various ways to get exposure to real estate, e.g., via real estate investment trusts (REITs), which often trade on major exchanges and allow investors to take a liquid stake in real estate.[204] There are several ways to measure a return from a real estate investment. A common and simple way is as follows:

$$R(t_1, t_2) = \frac{P(t_2) + C(t_1, t_2)}{P(t_1)} - 1 \tag{520}$$

Here: $R(t_1, t_2)$ is the return of the investment from the beginning of the holding period t_1 to the end of the holding period t_2; $P(t_1)$ and $P(t_2)$ are the market values of the property at those times; $C(t_1, t_2)$ is the cash flows received, net of costs.[205]

16.2 Strategy: Mixed-asset diversification with real estate

Real estate assets are attractive as a tool for diversification. Empirical studies suggest that their correlation with traditional assets, such as bonds and stocks, is low and remains such even through extreme market events (e.g., financial crises),

[202] See, e.g., [Barroso and Santa-Clara, 2014], [Blitz, Huij and Martens, 2011], [Daniel and Moskowitz, 2016].

[203] Or, more simply, 100% of the investment could be allocated without leverage, in which case the prefactor in Eq. (519) is $\min(\sigma_{target}/\widehat{\sigma}, 1)$ instead.

[204] REITs are in a sense similar to mutual funds as they provide a way for individual investors to acquire ownership in income-generating real estate portfolios.

[205] For some literature, see, e.g., [Block, 2011], [Eldred, 2004], [Geltner, Rodriguez and O'Connor, 1995], [Goetzmann and Ibbotson, 1990], [Hoesli and Lekander, 2008], [Hudson-Wilson *et al*, 2005], [Larkin, Babin and Rose, 2004], [Mazurczak, 2011], [Pivar, 2003], [Steinert and Crowe, 2001].

when the correlations between traditional assets tend to increase. In addition, the correlation tends to be lower at longer time horizons, so long-term investors may improve their portfolio performance in terms of risk-adjusted returns by including real estate assets (see, e.g., [Feldman, 2003], [Geltner *et al*, 2006], [Seiler, Webb and Myer, 1999], [Webb, Curcio and Rubens, 1988]). So, a simple strategy amounts to buying and holding real estate assets within a traditional portfolio containing, e.g., bonds, equities, etc. The optimal allocation varies depending on investor preferences (in terms of risk and return) and the horizon (see, e.g., [Geltner, Rodriguez and O'Connor, 1995], [Lee and Stevenson, 2005], [Mueller and Mueller, 2003], [Rehring, 2012]), and techniques such as mean-variance optimization or vector autoregressive model (VAR)[206] can be used to calculate the optimal allocation conditional on the time horizon and desired performance characteristics (see, e.g., [Fugazza, Guidolin and Nicodano, 2007], [Hoevenaars *et al*, 2008], [MacKinnon and Al Zaman, 2009]).

16.3 Strategy: Intra-asset diversification within real estate

This strategy amounts to diversifying real estate holdings (which can be part of a larger portfolio as in Subsection 16.2). Real estate assets can be diversified by geographic area, type of property, size, proximity to a metropolitan area, economic region, etc. (see, e.g., [Eichholtz *et al*, 1995], [Hartzell, Hekman and Miles, 1986], [Hartzell, Shulman and Wurtzebach, 1987], [Hudson-Wilson, 1990], [Seiler, Webb and Myer, 1999], [Viezer, 2000]). Various standard portfolio construction techniques (such as those mentioned in Subsection 16.2) can be applied to determine allocations.

16.3.1 Strategy: Property type diversification

This strategy amounts to investing in real estate assets of different types, e.g., apartments, offices, industrial properties (which include manufacturing buildings and property), shopping centers, etc. Empirical studies suggest that property type diversification can be beneficial for non-systematic risk reduction after taking into account transaction costs (see, e.g., [Firstenberg, Ross and Zisler, 1988], [Grissom, Kuhle and Walther, 1987], [Miles and McCue, 1984], [Mueller and Laposa, 1995]).

16.3.2 Strategy: Economic diversification

This strategy amounts to diversifying real estate investments by different regions divided according to economic characteristics such as the main economic activity, employment statistics, average income, etc. Empirical studies suggest that such diversification can reduce non-systematic risk and transaction costs (see, e.g., [Hartzell, Shulman and Wurtzebach, 1987], [Malizia and Simons, 1991], [Mueller, 1993]).

[206] For some literature on the VAR approach, see, e.g., [Barberis, 2000], [Campbell, 1991], [Campbell, Chan and Viceira, 2003], [Campbell and Viceira, 2004], [Campbell and Viceira, 2005], [Kandel and Stambaugh, 1987], [Sørensen and Trolle, 2005].

16.3.3 Strategy: Property type and geographic diversification

This strategy combines diversification based on more than one attribute, e.g., property type and region. Thus, if we consider four property types, to wit, office, retail, industrial and residential, and four U.S. regions, to wit, East, Midwest, South, and West, we can diversify across the resultant 16 groups (see, e.g., [Viezer, 2000]).[207]

16.4 Strategy: Real estate momentum – regional approach

This strategy amounts to buying real estate properties based on their past returns. Empirical evidence suggests that there is a momentum effect across the U.S. metropolitan statistical areas (MSAs), i.e., areas with higher (lower) past returns tend to continue to deliver higher (lower) returns in the future (see, e.g., [Beracha and Downs, 2015], [Beracha and Skiba, 2011]). In some cases, a zero-cost strategy can be constructed, e.g., by using alternative real estate vehicles such as REITs, and futures and options on U.S. housing indices based on different geographical areas.[208]

16.5 Strategy: Inflation hedging with real estate

Empirical studies suggest a strong relationship between the real estate returns and inflation rate. Therefore, real estate can be used as a hedge against inflation. Further, empirically, some property types (e.g., commercial real estate, which tends to adjust faster to inflationary price increases) appear to provide a better hedge than others, albeit this can depend on various aspects such as the sample, market, etc.[209]

[207] For some additional pertinent literature, see, e.g., [De Wit, 2010], [Ertugrul and Giambona, 2011], [Gatzlaff and Tirtiroglu, 1995], [Hartzell, Eichholtz and Selender, 2007], [Hastings and Nordby, 2007], [Ross and Zisler, 1991], [Seiler, Webb and Myer, 1999], [Worzala and Newell, 1997].

[208] For some literature on real estate momentum strategies (including using REITs and other investment vehicles mentioned above) and related topics, see, e.g., [Abraham and Hendershott, 1993], [Abraham and Hendershott, 1996], [Anglin, Rutherford and Springer, 2003], [Buttimer, Hyland and Sanders, 2005], [Caplin and Leahy, 2011], [Capozza, Hendershott and Mack, 2004], [Case and Shiller, 1987], [Case and Shiller, 1989], [Case and Shiller, 1990], [Chan, Hendershott and Sanders, 1990], [Chan, Leung and Wang, 1998], [Chen *et al*, 1998], [Cho, 1996], [Chui, Titman and Wei, 2003a], [Chui, Titman and Wei, 2003b], [Cooper, Downs and Patterson, 1999], [Derwall *et al*, 2009], [de Wit and van der Klaauw, 2013], [Genesove and Han, 2012], [Genesove and Mayer, 1997], [Genesove and Mayer, 2001], [Goebel *et al*, 2013], [Graff, Harrington and Young, 1999], [Graff and Young, 1997], [Gupta and Miller, 2012], [Guren, 2014], [Haurin and Gill, 2002], [Haurin *et al*, 2010], [Head, Lloyd-Ellis and Sun, 2014], [Kallberg, Liu and Trzcinka, 2000], [Kang and Gardner, 1989], [Karolyi and Sanders, 1998], [Knight, 2002], [Krainer, 2001], [Kuhle and Alvayay, 2000], [Lee, 2010], [Levitt and Syverson, 2008], [Li and Wang, 1995], [Lin and Yung, 2004], [Liu and Mei, 1992], [Malpezzi, 1999], [Meen, 2002], [Mei and Gao, 1995], [Mei and Liao, 1998], [Moss *et al*, 2015], [Nelling and Gyourko, 1998], [Novy-Marx, 2009], [Ortalo-Magné and Rady, 2006], [Piazzesi and Schneider, 2009], [Peterson and Hsieh, 1997], [Poterba and Sinai, 2008], [Smith and Shulman, 1976], [Stein, 1995], [Stevenson, 2001], [Stevenson, 2002], [Taylor, 1999], [Titman and Warga, 1986], [Wheaton, 1990], [Yavas and Yang, 1995], [Young and Graff, 1996].

[209] For some pertinent literature, see, e.g., [Bond and Seiler, 1998], [Fama and Schwert, 1977], [Gunasekarage, Power and Zhou, 2008], [Hamelink and Hoesli, 1996], [Hartzell, Hekman and Miles,

16.6 Strategy: Fix-and-flip

This is a short-term real estate investment strategy. It amounts to purchasing a property, which typically is in a distressed condition and requires renovations, at a (substantial) discount below market prices. The investor renovates the property and resells it at a price high enough to cover the renovation costs and make a profit.[210]

17 Cash

17.1 Generalities

Cash is an asset, albeit at times its function as an asset might be overlooked or taken for granted. As an asset, cash can be used in a variety of ways, e.g., i) as a *risk management tool*, as it can help mitigate drawdowns and volatility; ii) as an *opportunity management tool*, as it allows to take advantage of specific or unusual situations; and iii) as a *liquidity management tool* in unexpected situations that require liquid funds. There are several ways to include liquid funds in a portfolio, e.g., via U.S. Treasury bills, bank deposit certificates (CDs), commercial paper, banker's acceptances, eurodollars, and repurchase agreements (a.k.a. repos), etc.[211]

17.2 Strategy: Money laundering – the dark side of cash

Money laundering, broadly, is an activity wherein cash is used as a vehicle to transform illegal profits into legitimate-appearing assets. There are three main steps in a money laundering process. The first and the riskiest step is the *placement*, whereby illegal funds are introduced into the legal economy via fraudulent means, e.g., by dividing funds into small amounts and depositing them into multiple bank accounts thereby avoiding detection. The second step, *layering*, involves moving the money around between different accounts and even countries thereby creating complexity and separating the money from its source by several degrees. The third step is *integration*, whereby money launderers get back the money via legitimate-looking sources, e.g., cash-intensive businesses such as bars and restaurants, car washes, hotels (at least in some countries), gambling establishments, parking garages, etc.[212]

1987], [Le Moigne and Viveiros, 2008], [Mauer and Sebastian, 2002], [Miles and Mahoney, 1997], [Newell, 1996], [Sing and Low, 2000], [Wurtzebach, Mueller and Machi, 1991].

[210] For some pertinent literature, see, e.g., [Anacker, 2009], [Anacker and Schintler, 2015], [Bayer *et al*, 2015], [Chinco and Mayer, 2012], [Corbett, 2006], [Depken, Hollans and Swidler, 2009], [Depken, Hollans and Swidler, 2011], [Fu and Qian, 2014], [Hagopian, 1999], [Kemp, 2007], [Leung and Tse, 2013], [Montelongo and Chang, 2008], [Villani and Davis, 2006].

[211] For some literature, see, e.g., [Cook and LaRoche, 1993], [Cook and Rowe, 1986], [Damiani, 2012], [Duchin, 2010], [Goodfriend, 2011], [Schaede, 1990], [Summers, 1980], [Ysmailov, 2017].

[212] For some literature, see, e.g., [Ardizzi *et al*, 2014], [Cox, 2015], [Gilmour and Ridley, 2015], [Hopton, 1999], [John and Brigitte, 2009], [Kumar, 2012], [Levi and Reuter, 2006], [Schneider and Windischbauer, 2008], [Seymour, 2008], [Soudijn, 2016], [Walker, 1999], [Wright *et al*, 2017].

17.3 Strategy: Liquidity management

From a portfolio management perspective, this strategy amounts to optimally defining the amount of cash to be held in the portfolio to meet liquidity demands generated by unforeseen events.[213] Cash provides immediate liquidity, whereas other assets would have to be liquidated first, which can be associated with substantial transaction costs, especially if liquidation is abrupt.[214] From a corporate perspective, holding cash can be a precautionary measure aimed at avoiding cash flow shortfalls that can yield, inter alia, loss of investment opportunities, financial distress, etc.[215]

17.4 Strategy: Repurchase agreement (REPO)

A repurchase agreement (REPO) is 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. A reverse repurchase agreement is the opposite. So, a REPO strategy amounts to borrowing (lending) cash with interest in exchange for securities with the commitment of repurchasing them from (reselling them to) the counterparty. This type of a transaction typically spans from 1 day to 6 months.[216]

17.5 Strategy: Pawnbroking

REPOs are in some sense similar to much more ancient pawnbroking strategies. A pawnbroker extends a secured cash loan with pre-agreed interest and period (which can sometimes be extended). The loan is secured with a collateral, which is some valuable item(s), such as jewelry, electronics, vehicles, rare books or musical instruments, etc. If the loan is not repaid with interest as agreed, then the collateral is forfeited by the borrower and the pawnbroker can keep it or sell it. The amount of loan typically is at a significant discount to the appraised value of the collateral.[217]

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[213] Note that this is not necessarily the same reason for holding cash as that behind Kelly strategies. For some pertinent literature, see, e.g., [Browne, 2000], [Cover, 1984], [Davis and Lleo, 2012], [Hsieh and Barmish, 2015], [Hsieh, Barmish and Gubner, 2016], [Kelly, 1956], [Laureti, Medo and Zhang, 2010], [Lo, Orr and Zhang, 2017], [Maslov and Zhang, 1998], [Nekrasov, 2014], [Rising and Wyner, 2012], [Samuelson, 1971], [Thorp, 2006], [Thorp and Kassouf, 1967].

[214] For some literature, see, e.g., [Agapova, 2011b], [Aragon *et al*, 2017], [Cao *et al*, 2013], [Chernenko and Sunderam, 2016], [Connor and Leland, 1995], [Jiang, Li and Wang, 2017], [Kruttli, Monin and Watugala, 2018], [Leland and Connor, 1995], [Simutin, 2014], [Yan, 2006].

[215] For some literature on corporate aspects of liquidity management and related topics, see, e.g., [Acharya, Almeida and Campello, 2007], [Almeida, Campello and Weisbach, 2005], [Azmat and Iqbal, 2017], [Chidambaran, Fernando and Spindt, 2001], [Disatnik, Duchin and Schmidt, 2014], [Froot, Scharfstein and Stein, 1993], [Han and Qiu, 2007], [Opler *et al*, 1999], [Sher, 2014].

[216] See, e.g., [Adrian *et al*, 2013], [Bowsher, 1979], [Duffie, 1996], [Garbade, 2004], [Gorton and Metrick, 2012], [Happ, 1986], [Kraenzlin, 2007], [Lumpkin, 1987], [Ruchin, 2011], [Schatz, 2012], [Simmons, 1954], [Sollinger, 1994], [Zhang, Fargher and Hou, 2018].

[217] In Section 9 we discussed trading strategies based on commodity futures. Pawnbrokers, among other things, trade physical commodities such as silver and gold. For some literature on pawnbroking and related topics, see, e.g., [Bos, Carter and Skiba, 2012], [Bouman and Houtman,

17.6 Strategy: Loan sharking

Unlike pawnbroking, loan sharking in many jurisdictions is illegal. Loan sharking consists of offering a loan at excessively high interest rates. Such a loan is not necessarily secured by a collateral. Instead, a loan shark can sometimes resort to blackmail and/or violence to enforce the terms of a loan (see, e.g., [Aldohni, 2013]).

18 Cryptocurrencies

18.1 Generalities

Cryptocurrencies, such as Bitcoin (BTC), Ethereum (ETH), etc., unlike traditional fiat currencies (USD, EUR, etc.), are decentralized digital currencies based on open-source peer-to-peer (P2P) internet protocols. Cryptocurrencies such as BTC and ETH use the blockchain technology [Nakamoto, 2008].[218] Total market capitalization of cryptocurrencies is measured in hundreds of billions of dollars.[219] Many investors are attracted to cryptocurrencies as speculative buy-and-hold assets. Thus, some view them as diversifiers due to their low correlation with traditional assets. Others perceive them as the future of money. Some investors simply want to make a quick buck on a speculative bubble. Etc.[220] Be it as it may, unlike, e.g., stocks, there are no evident "fundamentals" for cryptoassets based on which one could build "fundamental" trading strategies (e.g., value-based strategies). So, cryptocurrency trading strategies tend to rely on trend data mining via machine learning techniques.

18.2 Strategy: Artificial neural network (ANN)

This strategy uses ANN to forecast short-term movements of BTC based on input technical indicators. In ANN we have an input layer, an output layer, and some

1988], [Caskey, 1991], [D'Este, 2014], [Fass and Francis, 2004], [Maaravi and Levy, 2017], [McCants, 2007], [Shackman and Tenney, 2006], [Zhou *et al*, 2016].

[218] Blockchain is a distributed ledger, which keeps a record of all transactions. It is a sequential chain of blocks, which are linked using cryptography and time-stamping, containing transaction records. No block can be altered retroactively without altering all subsequent blocks, which renders blockchain resistant to data modification by its very design. For a blockchain maintained by a large network as a distributed ledger continuously updated on a large number of systems simultaneously, collusion of the network majority would be required for a nefarious modification of blockchain.

[219] Cryptocurrencies are highly volatile, so their market cap has substantial time variability.

[220] For some pertinent literature, see, e.g., [Baek and Elbeck, 2014], [Bariviera *et al*, 2017], [Bouoiyour, Selmi and Tiwari, 2015], [Bouoiyour *et al*, 2016], [Bouri *et al*, 2017a], [Bouri *et al*, 2017b], [Brandvold *et al*, 2015], [Brière, Oosterlinck and Szafarz, 2015], [Cheah and Fry, 2015], [Cheung, Roca and Su, 2015], [Ciaian, Rajcaniova and Kancs, 2015], [Donier and Bouchaud, 2015], [Dowd and Hutchinson, 2015], [Dyhrberg, 2015], [Dyhrberg, 2016], [Eisl, Gasser and Weinmayer, 2015], [Fry and Cheah, 2016], [Gajardo, Kristjanpoller and Minutolo, 2018], [Garcia and Schweitzer, 2015], [Garcia *et al*, 2014], [Harvery, 2014], [Harvey, 2016], [Kim *et al*, 2016], [Kristoufek, 2015], [Lee, Guo and Wang, 2018], [Liew, Li and Budavári, 2018], [Ortisi, 2016], [Van Alstyne, 2014], [Wang and Vergne, 2017], [White, 2015].

number of hidden layers. So, in this strategy the input layer is built using technical indicators.[221] E.g., we can use (exponential) moving averages ((E)MAs), (exponential) moving standard deviations ((E)MSDs), relative strength index (RSI),[222] etc. More concretely, we can construct the input layer as follows (see, e.g., [Nakano, Takahashi and Takahashi, 2018]). Let $P(t)$ be the BTC price at time t, where $t = 1, 2, \dots$ is measured in some units (e.g., 15-minute intervals; also, $t = 1$ is the most recent time). Let:

$$R(t) = \frac{P(t)}{P(t+1)} - 1 \tag{521}$$

$$\widetilde{R}(t, T_1) = R(t) - \overline{R}(t, T_1) \tag{522}$$

$$\overline{R}(t, T_1) = \frac{1}{T_1} \sum_{t'=t+1}^{t+T_1} R(t') \tag{523}$$

$$\widehat{R}(t, T_1) = \frac{\widetilde{R}(t, T_1)}{\sigma(t, T_1)} \tag{524}$$

$$[\sigma(t, T_1)]^2 = \frac{1}{T_1 - 1} \sum_{t'=t+1}^{t+T_1} [\widetilde{R}(t, T_1)]^2 \tag{525}$$

So: $R(t)$ is the return from $t+1$ to t; $\overline{R}(t, T_1)$ is the serial mean return from $t + T_1$ to $t+1$, i.e., over T_1 periods, where T_1 can be chosen to be long enough to provide a reasonable estimate for the volatility (see below); $\widetilde{R}(t, T_1)$ is the serially demeaned return; $\sigma(t, T_1)$ is the volatility computed from $t + T_1$ to $t + 1$; and $\widehat{R}(t, T_1)$ is the normalized (serially demeaned) return. Below, for notational simplicity we will omit the reference to the T_1 parameter and will use $\widehat{R}(t)$ to denote the normalized returns.

Next, we can define EMAs, EMSDs and RSI as follows:[223]

$$\text{EMA}(t, \lambda, \tau) = \frac{1 - \lambda}{1 - \lambda^\tau} \sum_{t'=t+1}^{t+\tau} \lambda^{t'-t-1}\ \widehat{R}(t') \tag{526}$$

$$[\text{EMSD}(t, \lambda, \tau)]^2 = \frac{1 - \lambda}{\lambda - \lambda^\tau} \sum_{t'=t+1}^{t+\tau} \lambda^{t'-t-1}\ [\widehat{R}(t') - \text{EMA}(t, \lambda, \tau)]^2 \tag{527}$$

$$\text{RSI}(t, \tau) = \frac{\nu_+(t, \tau)}{\nu_+(t, \tau) + \nu_-(t, \tau)} \tag{528}$$

$$\nu_\pm(t, \tau) = \sum_{t'=t+1}^{t+\tau} \max(\pm \widehat{R}(t'), 0) \tag{529}$$

Here: τ is the moving average length; λ is the exponential smoothing parameter.[224]

[221] Thus, in spirit, it is somewhat similar to the single-stock KNN trading strategy discussed in Subsection 3.17, which utilizes the k-nearest neighbor (KNN) algorithm (as opposed to ANN).

[222] Typically, RSI > 0.7 (< 0.3) is interpreted as overbought (oversold). See, e.g., [Wilder, 1978].

[223] Note that this can be done in more than one way.

[224] To reduce the number of parameters, we can, e.g., take $\lambda = (\tau - 1)/(\tau + 1)$.

The input layer can then be defined as consisting of, e.g., $\widehat{R}(t)$, $\text{EMA}(t, \lambda_a, \tau_a)$, $\text{EMSD}(t, \lambda_a, \tau_a)$, and $\text{RSI}(t, \tau'_{a'})$, where $a = 1, \dots, m$, $a' = 1, \dots, m'$. The values τ_a can, e.g., be chosen to correspond to 30 min, 1 hr, 3 hrs and 6 hrs (so $m = 4$; see fn. 224 for the values of λ_a). The values $\tau'_{a'}$ can, e.g., be chosen to correspond to 3 hrs, 6 hrs and 12 hrs (so $m' = 3$). There is no magic bullet here. These values can be chosen based on out-of-sample backtests keeping in mind, however, the ever-present danger of over-fitting various free parameters (see below), including τ_a, λ_a and $\tau'_{a'}$.

The output layer can be constructed as follows. Let the objective be to forecast which quantile the future normalized return will belong to. Let the number of quantiles be K. Thus, for the values of t corresponding to the training dataset D_{train},[225] we have the normalized returns $\widehat{R}(t)$, $t \in D_{train}$. Let the $(K-1)$ quantile values of $\widehat{R}(t)$, $t \in D_{train}$, be q_α, $\alpha = 1, \dots, (K-1)$. For each value of t, we can define the supervisory K-vectors $S_\alpha(t)$, $\alpha = 1, \dots, K$, as follows:

$$\begin{cases} S_1(t) = 1, & \widehat{R}(t) \leq q_1 \\ S_\alpha(t) = 1, & q_{\alpha-1} \leq \widehat{R}(t) < q_\alpha, \quad 1 < \alpha < K \\ S_K(t) = 1, & q_{K-1} \leq \widehat{R}(t) \\ S_\alpha(t) = 0, & \text{otherwise} \end{cases} \tag{530}$$

The output layer can then be a nonnegative K-vector $p_\alpha(t)$, whose elements are interpreted as the probabilities of the future normalized return to be in the α-th quantile. So, we have

$$\sum_{\alpha=1}^{K} p_\alpha(t) = 1 \tag{531}$$

The output layer is constructed from the input layer as some nonlinear function thereof with some number of parameters to be determined via training. In ANN we have L layers labeled by $\ell = 1, \dots, L$, where $\ell = 1$ corresponds to the input layer, and $\ell = L$ corresponds to the output layer. At each layer we have $N^{(\ell)}$ nodes and the corresponding $N^{(\ell)}$-vectors $\vec{X}^{(\ell)}$ with components $X^{(\ell)}_{i^{(\ell)}}$, $i^{(\ell)} = 1, \dots, N^{(\ell)}$:[226]

$$X^{(\ell)}_{i^{(\ell)}} = h^{(\ell)}_{i^{(\ell)}}(\vec{Y}^{(\ell)}), \quad \ell = 2, \dots, L \tag{532}$$

$$Y^{(\ell)}_{i^{(\ell)}} = \sum_{j^{(\ell-1)}=1}^{N^{(\ell-1)}} A^{(\ell)}_{i^{(\ell)} j^{(\ell-1)}} \; X^{(\ell-1)}_{j^{(\ell-1)}} + B^{(\ell)}_{i^{(\ell)}} \tag{533}$$

Here: $\vec{Y}^{(\ell)}$ is an $N^{(\ell)}$-vector with components $Y^{(\ell)}_{i^{(\ell)}}$, $i^{(\ell)} = 1, \dots, N^{(\ell)}$; $X^{(1)}_{i^{(1)}}$ are the input data (for each value of t, i.e., $\widehat{R}(t)$, $\text{EMA}(t, \lambda_a, \tau_a)$, $\text{EMSD}(t, \lambda_a, \tau_a)$, and $\text{RSI}(t, \tau'_{a'})$ – see above); $X^{(L)}_{i^{(L)}}$ are the output data $p_\alpha(t)$ (i.e., $N^{(L)} = K$ and the index

[225] Ideally, when computing the quantiles, an appropriate number d_1 of the values of $t = t_d, t_{d-1}, \dots, t_{d-d_1+1}$, $d = |D_{train}|$, should be excluded to ensure that all the EMA, EMSD and RSI values are computed using the required numbers of datapoints.

[226] We suppress the time variable t for the sake of notational simplicity.

$i^{(L)}$ is the same as α); the unknown parameters $A^{(\ell)}_{i^{(\ell)} j^{(\ell-1)}}$ (the so-called weights) and $B^{(\ell)}_{i^{(\ell)}}$ (the so-called bias) are determined via training (see below); and there is much arbitrariness in terms of picking the values of $N^{(\ell)}$ and the so-called activation functions $h^{(\ell)}_{i^{(\ell)}}$. A possible choice (out of myriad others) is as follows (see, e.g., [Nakano, Takahashi and Takahashi, 2018]):[227]

$$h^{(\ell)}_{i^{(\ell)}}(\vec{Y}^{(\ell)}) = \max\left(Y^{(\ell)}_{i^{(\ell)}}, 0\right), \quad \ell = 2, \dots, L-1 \quad \text{(ReLU)} \tag{534}$$

$$h^{(L)}_{i^{(L)}}(\vec{Y}^{(L)}) = Y^{(L)}_{i^{(L)}} \left[\sum_{j^{(L)}=1}^{N^{(L)}} Y^{(L)}_{j^{(L)}}\right]^{-1} \quad \text{(softmax)} \tag{535}$$

I.e., ReLU is used at the hidden layers (and the algorithm moves onto the next layer only if some neurons are activated (fired) at layer ℓ, i.e., at least some $Y^{(\ell)}_{i^{(\ell)}} > 0$), and softmax is used at the output layer (so that we have the condition (531) by construction). Further, to train the model, i.e., to determine the unknown parameters, some kind of error function E (we suppress its variables) must be minimized, e.g., the so-called cross-entropy (see, e.g., [de Boer *et al*, 2005]):

$$E = -\sum_{t \in D_{train}} \sum_{\alpha=1}^{K} S_\alpha(t)\ \ln(p_\alpha(t)) \tag{536}$$

To minimize E, one can, e.g., use the stochastic gradient descent (SGD) method, which minimizes the error function iteratively until the procedure converges.[228]

Finally, we must specify the trading rules. There are a number of possibilities here depending on the number of quantiles, i.e., the choice of K. A reasonable trading signal is given by:

$$\text{Signal} = \begin{cases} \text{Buy}, & \text{iff} \quad \max(p_\alpha(t)) = p_K(t) \\ \text{Sell}, & \text{iff} \quad \max(p_\alpha(t)) = p_1(t) \end{cases} \tag{537}$$

Therefore, the trader buys BTC if the predicted class is $p_K(t)$ (the top quantile), and sells if it is $p_1(t)$ (the bottom quantile). This trading rule can be modified. E.g., the buy signal can be based on the top 2 quantiles, and the sell signal can be based on the bottom 2 quantiles (see, e.g., [Nakano, Takahashi and Takahashi, 2018]).[229]

[227] Again, there is no magic bullet here. A priori, a host of activation functions can be used, e.g., sigmoid (a.k.a. logistic), tanh (hyperbolic tangent), rectified linear unit (ReLU), softmax, etc. For some pertinent literature, see, e.g., [Bengio, 2009], [Chandra, 2003], [da S. Gomes, Ludermir and Lima, 2011], [Glorot, Bordes and Bengio, 2011], [Goodfellow *et al*, 2013], [Karlik and Vehbi, 2011], [Mhaskar and Micchelli, 1993], [Singh and Chandra, 2003], [Wu, 2009].

[228] A variety of methods can be used. For some pertinent literature, see, e.g., [Denton and Hung, 1996], [Dong and Zhou, 2008], [Dreyfus, 1990], [Ghosh, 2012], [Kingma and Ba, 2014], [Ruder, 2017], [Rumelhart, Hinton and Williams, 1986], [Schmidhuber, 2015], [Wilson *et al*, 2018].

[229] Various techniques used in applying ANNs to other asset classes such as equities may also be useful for cryptocurrencies. See, e.g., [Ballings *et al*, 2015], [Chong, Han and Park, 2017], [Dash and Dash, 2016], [de Oliveira, Nobre and Zárate, 2013], [Sezer, Ozbayoglu and Dogdu, 2017], [Yao, Tan and Poh, 1999]. For some additional literature, see fn. 61.

18.3 Strategy: Sentiment analysis – naïve Bayes Bernoulli

Social media sentiment analysis based strategies have been used in stock trading[230] and also applied to cryptocurrency trading. The premise is to use a machine learning classification scheme to forecast, e.g., the direction of the BTC price movement based on tweet data. This entails collecting all tweets containing at least one keyword from a pertinent (to BTC price forecasting) learning vocabulary V over some timeframe, and cleaning this data.[231] The resultant data is then further processed by assigning a so-called feature (M-vector) X_i to each tweet labeled by $i = 1, \dots, N$, where N is the number of tweets in the dataset. Here $M = |V|$ is the number of keywords in the learning vocabulary V. So, the components of each vector X_i are X_{ia}, where $a = 1, \dots, M$ labels the words in V. Thus, if the word $w_a \in V$ labeled by a is not present in the tweet T_i labeled by i, then $X_{ia} = 0$. If w_a is present in T_i, then we can set $X_{ia} = 1$ or $X_{ia} = n_{ia}$, where n_{ia} counts the number of times w_a appears in T_i. In the former case (which is what we focus on in the following) we have a Bernoulli probability distribution, while in the latter case we have a multinomial distribution.

Next, we need to build a model that, given the N feature vectors X_i, predicts one out of a preset number K of outcomes (so-called *classes*) C_α, $\alpha = 1, \dots, K$. E.g., we can have $K = 2$ outcomes, whereby BTC is forecasted to go up or down, which can be used as the buy/sell signal. Alternatively, as in the ANN strategy in Subsection 18.2, we can have K quantiles for the normalized returns $\widehat{R}(t)$. Etc. This then defines our trading rules. Once the classes C_α are chosen, a simple way to forecast them is to build a model for conditional probabilities $P(C_\alpha | X_1, \dots, X_N)$. Here, generally, $P(A|B)$ denotes the conditional probability of A occurring assuming B is true. Pursuant to Bayes' theorem, we have

$$P(A|B) = \frac{P(B|A)\ P(A)}{P(B)} \tag{538}$$

where $P(A)$ and $P(B)$ are the probabilities of A and B occurring independently of each other. So, we have

$$P(C_\alpha | X_1, \dots, X_N) = \frac{P(X_1, \dots, X_N | C_\alpha)\ P(C_\alpha)}{P(X_1, \dots, X_N)} \tag{539}$$

Note that $P(X_1, \dots, X_N)$ is independent of C_α and will not be important below. Now, $P(C_\alpha)$ can be estimated from the training data. The primary difficulty is in

[230] For some literature, see, e.g., [Bollen and Mao, 2011], [Bollen, Mao and Zeng, 2011], [Kordonis, Symeonidis and Arampatzis, 2016], [Liew and Budavári, 2016], [Mittal and Goel, 2012], [Nisar and Yeung, 2018], [Pagolu *et al*, 2016], [Rao and Srivastava, 2012], [Ruan, Durresi and Alfantoukh, 2018], [Sprenger *et al*, 2014], [Sul, Dennis and Yuan, 2017]), [Zhang, Fuehres and Gloor, 2011].

[231] This, among other things, includes removing duplicate tweets likely generated by ubiquitous Twitter bots, removing the so-called *stop-words* (e.g., "the", "is", "in", "which", etc.), which do not add value, from the tweets, and performing the so-called *stemming*, i.e., reducing words to their base form (e.g., "investing" and "invested" are reduced to "invest", etc.). The latter can be achieved using, e.g., the Porter stemming algorithm or other similar algorithms (for some literature, see, e.g., [Hull, 1996], [Porter, 1980], [Raulji and Saini, 2016], [Willett, 2006]).

estimating $P(X_1, \dots, X_N|C_\alpha)$. Here a simplification occurs if we make the "naïve" conditional independence assumption (hence the term "naïve Bayes"), i.e., that, given the class C_α, for all i the feature X_i is conditionally independent of every other feature X_j, $j = 1, \dots, N$ ($j \neq i$):

$$P(X_i|C_\alpha, X_1, \dots, X_{i-1}, X_{i+1}, \dots, X_N) = P(X_i|C_\alpha) \tag{540}$$

Then Eq. (539) simplifies as follows:

$$P(C_\alpha|X_1, \dots, X_N) = \gamma\ P(C_\alpha)\ \prod_{i=1}^{N} P(X_i|C_\alpha) \tag{541}$$

$$\gamma = 1/P(X_1, \dots, X_N) \tag{542}$$

The conditional probabilities $P(X_i|C_\alpha)$ can be estimated using the conditional probabilities $P(w_a|C_\alpha)$ for the M words w_a in the learning vocabulary V:

$$P(X_i|C_\alpha) = \prod_{a=1}^{M} Q_{ia\alpha} \tag{543}$$

$$Q_{ia\alpha} = P(w_a|C_\alpha), \quad X_{ia} = 1 \tag{544}$$

$$Q_{ia\alpha} = 1 - P(w_a|C_\alpha), \quad X_{ia} = 0 \tag{545}$$

The conditional probabilities $P(w_a|C_\alpha)$ can simply be estimated based on the occurrence frequencies of the words w_a in the training data. Similarly, the probabilities $P(C_\alpha)$ can be estimated from the training data.[232] So, if we set the forecasted value C_{pred} of the outcome to that with the maximum $P(C_\alpha|X_1, \dots, X_N)$, then

$$C_{pred} = \text{argmax}_{C_\alpha \in \{1,\dots,K\}} P(C_\alpha)\ \prod_{i=1}^{N}\prod_{a=1}^{M} [P(w_a|C_\alpha)]^{X_{ia}} [1 - P(w_a|C_\alpha)]^{1-X_{ia}} \tag{546}$$

19 Global Macro

19.1 Generalities

Actually, macro trading strategies constitute an investment style, not an asset class. These types of strategies are not limited to any particular asset class or a geographical region and can invest in stocks, bonds, currencies, commodities, derivatives, etc.,

[232] For some literature on applying Twitter sentiment to Bitcoin trading, see, e.g., [Colianni, Rosales and Signorotti, 2015], [Georgoula *et al*, 2015], which also discuss other machine learning methods such as support vector machines (SVM) and logistic regression (a.k.a. logit model). For some literature on Bitcoin trading using other sentiment data, see, e.g., [Garcia and Schweitzer, 2015], [Li *et al*, 2018]. For some literature on applying tree boosting algorithms to cryptocurrency trading, see, e.g., [Alessandretti *et al*, 2018], [Li *et al*, 2018]. For some additional pertinent literature (which generally appears to be relatively scarce for BTC compared with similar literature on stock trading), see, e.g., [Amjad and Shah, 2017], [Jiang and Liang, 2017], [Shah and Zhang, 2014].

seeking to capitalize on regional, economic and political changes around the world. While many macro strategies are based on analysts' subjective opinions (these are discretionary strategies), a systematic approach (non-discretionary strategies) also plays a prominent role. Global macro strategies can vary by their style, e.g., there are directional strategies, long-short strategies, relative value strategies, etc.[233]

19.2 Strategy: Fundamental macro momentum

This strategy aims to capture returns from the market underreaction to changes in macroeconomic trends by buying (selling) assets favored (adversely affected) by incoming macroeconomic trends. Different asset classes can be used in building an investment portfolio, e.g., global equity indexes, currencies, government bonds, etc.[234] The "state variables" to consider are the business cycle, international trade, monetary policy, and risk sentiment trends (see, e.g., [Brooks, 2017]).[235] E.g., equity indexes from some number of countries are ranked using the values of the aforesaid 4 state variables for each country.[236] A zero-cost portfolio can then be constructed by, e.g., going long the indexes in the top decile and shorting those in the bottom decile. The so-constructed portfolios for various asset classes can, e.g., be combined with equal weights. Typically, the holding period ranges from three to six months.

19.3 Strategy: Global macro inflation hedge

Exogenous shocks (such as a political or geopolitical issue) can have an impact on commodity prices such as oil leading to an increase in prices in oil-dependent economies. There are two steps in this process: (i) a pass-through from commodity prices to the headline inflation (HI), and (ii) then, a pass-through from HI to the core inflation (CI).[237] I.e., HI quickly reflects various shocks around the world. So,

[233] Macro strategies can be divided into 3 classes: discretionary macro, systematic macro, and CTA/managed futures. For some literature on macro strategies and related topics, see, e.g., [Asgharian *et al*, 2004], [Chung, 2000], [Connor and Woo, 2004], [Dobson, 1984], [Drobny, 2006], [Fabozzi, Focardi and Jonas, 2010], [Fung and Hsieh, 1999], [Gliner, 2014], [Kidd, 2014], [Lambert, Papageorgiou and Platania, 2006], [Potjer and Gould, 2007], [Stefanini, 2006], [Zaremba, 2014].

[234] Different asset classes are affected by the same macroeconomic trends differently. E.g., increasing growth is positive for equities and currencies, but negative for bonds.

[235] Business cycle trends can be estimated using 1-yr changes in the real GDP growth and CPI inflation forecast, each contributing with a 50% weight. International trade trends can be estimated using 1-yr changes in spot FX rates against an export-weighted basket. Monetary policy trends can be estimated using 1-yr changes in short-term rates. Risk sentiment trends can be estimated using 1-yr equity market excess returns. For some literature on the rationale behind these variables, see, e.g., [Bernanke and Kuttner, 2005], [Clarida and Waldman, 2007], [Eichenbaum and Evans, 1995].

[236] There is a variety of ways to do this ranking using the 4 variables. See, e.g., Subsection 3.6.

[237] HI is the raw inflation measured by indices such as the Consumer Price Index (CPI) based on prices of goods and services in a broad basket, while CI excludes some products such as commodities, which are highly volatile and add sizable noise to the index. For some pertinent literature, see, e.g., [Blanchard and Gali, 2007], [Blanchard and Riggi, 2013], [Clark and Terry, 2010], [Hamilton, 2003], [Marques, Neves and Sarmento, 2003], [Trehan, 2005], [van den Noord and André, 2004].

the global macro inflation hedge strategy is based on the spread between HI and CI as an indicator to hedge inflation using commodities:[238]

$$\mathrm{CA} = \max\left(0, \min\left(\frac{\mathrm{HI}_{YoY} - \mathrm{CI}_{YoY}}{\mathrm{HI}_{YoY}}, 1\right)\right) \quad (547)$$

Here: CA is the commodity allocation percentage within the portfolio, and "YoY" stands for "year-on-year". The hedge can be executed by, e.g., buying a basket of various commodities through ETFs, futures, etc. (see, e.g., [Fulli-Lemaire, 2013]).

19.4 Strategy: Global fixed-income strategy

This systematic macro trading strategy is based on a cross-sectional analysis of government bonds from various countries using variables such as (see, e.g., [Brück and Fan, 2017]) GDP, inflation, sovereign risk, real interest rate, output gap, value, momentum, term spread, and the so-called Cochrane-Piazzesi predictor [Cochrane and Piazzesi, 2005]. Thus, said bonds can be ranked based on these factors and a zero-cost portfolio can be constructed by buying bonds in the top quantile and selling bonds in the bottom quantile. Similarly to Subsection 3.6, multifactor portfolios can also be constructed. Typically, country-bond ETFs are used in such portfolios.[239]

19.5 Strategy: Trading on economic announcements

Empirical evidence suggests that stocks tend to yield higher returns on important announcement dates such Federal Open Market Committee (FOMC) announcements.[240] So, a simple macro trading strategy consists of buying stocks on important announcement days (ADs), such as the FOMC announcements, and switching to risk-free assets during non-announcement days (NDAs). This is done via ETFs, futures, etc., as opposed to individual stocks, as the strategy involves moving from 100% allocated in equities to 100% allocated in Treasuries (see, e.g., [Stotz, 2016]).[241]

20 Infrastructure

Broadly, investing in infrastructure includes investing in long-term projects such as transportation (roads, bridges, tunnels, railways, ports, airports, etc.), telecommuni-

[238] For some literature on using commodities as an inflation hedge, see, e.g., [Amenc, Martellini and Ziemann, 2009], [Bodie, 1983], [Bodie and Rosansky, 1980], [Greer, 1978], [Hoevenaars *et al*, 2008], [Jensen, Johnson and Mercer, 2002].

[239] For some literature on factor investing in fixed-income assets, see, e.g., [Beekhuizen *et al*, 2016], [Correia, Richardson and Tuna, 2012], [Houweling and van Vundert, 2017], [Koijen, Moskowitz, Pedersen and Vrugt, 2018], [L'Hoir and Boulhabel, 2010], [Staal *et al*, 2015].

[240] For some pertinent literature, see, e.g., [Ai and Bansal, 2016], [Bernanke and Kuttner, 2005], [Boyd, Hu and Jagannathan, 2005], [Donninger, 2015], [Graham, Nikkinen and Sahlström, 2003], [Jones, Lamont and Lumsdaine, 1998], [Lucca and Moench, 2012], [Savor and Wilson, 2013].

[241] This strategy can be augmented with various (e.g., technical) filters (see, e.g., [Stotz, 2016]).

cations (transmission cables, satellites, towers, etc.), utilities (electricity generation, gas or electricity transmission or distribution, water supply, sewage, waste, etc.), energy (including but not limited to renewable energy), healthcare (hospitals, clinics, senior homes, etc.), educational facilities (schools, universities, research institutes, etc.), etc. An investor can gain exposure to infrastructure assets through different direct or indirect investments such private equity-type investments (e.g., via unlisted infrastructure funds), listed infrastructure funds, stocks of publicly traded infrastructure companies, municipal bonds earmarked to infrastructure projects, etc.[242]

Infrastructure investments, by their nature, are long-term, buy-and-hold investments. One investment strategy is to use infrastructure assets to improve risk-adjusted returns of well-diversified portfolios, e.g., via tracking ETFs, global infrastructure funds, unlisted infrastructure funds, etc.[243] Another investment strategy is to use infrastructure assets for inflation hedging.[244] Yet another investment strategy is to generate stable cash flows from infrastructure investments. For this purpose, "brownfield" projects (associated with established assets in need of improvement) are more appropriate than "greenfield" projects (associated with assets to be constructed). Diversification across different sectors can be beneficial in this regard.[245]

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[242] For some literature on infrastructure as an asset class and related topics, see, e.g., [Ansar *et al*, 2016], [Bitsch, Buchner and Kaserer, 2010], [Blanc-Brude, Hasan and Whittaker, 2016], [Blanc-Brude, Whittaker and Wilde, 2017], [Blundell, 2006], [Clark, 2017], [Clark *et al*, 2012], [Finkenzeller, Dechant and Schäfers, 2010], [Grigg, 2010], [Grimsey and Lewis, 2002], [Hartigan, Prasad and De Francesco, 2011], [Helm, 2009], [Helm and Tindall, 2009], [Herranz-Loncán, 2007], [Inderst, 2010a], [McDevitt and Kirwan, 2008], [Newell, Chau and Wong, 2009], [Newell and Peng, 2008], [Peng and Newell, 2007], [Ramamurti and Doh, 2004], [Rickards, 2008], [Sanchez-Robles, 1998], [Sawant, 2010a], [Sawant, 2010b], [Singhal, Newell and Nguyen, 2011], [Smit and Trigeorgis, 2009], [Torrance, 2007], [Vives, 1999], [Weber, Staub-Bisang and Alfen, 2016], [Wurstbauer *et al*, 2016].

[243] See, e.g., [Dechant and Finkenzeller, 2013], [Haran *et al*, 2011], [Joshi and Lambert, 2011], [Martin, 2010], [Nartea and Eves, 2010], [Newell, Peng and De Francesco, 2011], [Oyedele, Adair and McGreal, 2014], [Panayiotou and Medda, 2016], [Rothballer and Kaserer, 2012].

[244] Infrastructure, as real estate, can be an inflation-hedging investment, albeit apparently with some heterogeneity. For some literature, see, e.g., [Armann and Weisdorf, 2008], [Bird, Liem and Thorp, 2014], [Inderst, 2010b], [Wurstbauer and Schäfers, 2015], [Rödel and Rothballer, 2012].

[245] For some pertinent literature, see, e.g., [Arezki and Sy, 2016], [Espinoza and Luccioni, 2002], [Leigland, 2018], [Panayiotou and Medda, 2014], [Weber, Adair and McGreal, 2008].

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,[246] albeit for this kind of strategies – precisely because these are intraday strategies – the survivorship bias is not detrimental (see, e.g., [Kakushadze, 2015b]).[247]

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 $i = 1, \dots, N$ 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.[248] 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

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

[246] 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.

[247] 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].

[248] 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%),[249] 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[250] `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

[249] This amounts to assuming that, to establish an equally-weighted portfolio, it costs 10 bps.

[250] 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 $t = 1, 2, \dots, T$, 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 $t = 1, 2, \dots, T$ 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 $t = 1, 2, \dots, T$); $P_i^C(t)$ is the raw close price (which is the corresponding element of `close` for $t = 1, 2, \dots, T$); $P_i^{AC}(t)$ is the fully adjusted close price (which is the corresponding element of `prc` for $t = 1, 2, \dots, T$); $\gamma_i^{adj}(t)$ 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., $P_i^O(t)$, $t = 1, \dots, T$, 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, "insampleness" 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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References

Abken, P.A. (1989) An analysis of intra-market spreads in heating oil futures. *Journal of Futures Markets* 9(1): 77-86.

Abken, P.A. and Nandi, S. (1996) Options and Volatility. *Federal Reserve Bank of Atlanta, Economic Review* 81(3): 21-35.

Abraham, J.M. and Hendershott, P.H. (1993) Patterns and Determinants of Metropolitan House Prices, 1977 to 1991. In: Browne, L.E. and Rosengren, E.S. (eds.) *Real Estate and the Credit Crunch.* Boston, MA: Federal Reserve Bank of Boston, pp. 18-42.

Abraham, J.M. and Hendershott, P.H. (1996) Bubbles in Metropolitan Housing Markets. *Journal of Housing Research* 7(2): 191-207.

Abreu, D. and Brunnermeier, M.K. (2002) Synchronization risk and delayed arbitrage. *Journal of Financial Economics* 66(2-3): 341-360.

Accominotti, O. and Chambers, D. (2014) Out-of-Sample Evidence on the Returns to Currency Trading. *Working Paper.* Available online: `https://ssrn.com/abstract=2293684`.

Acharya, V.V., Almeida, H. and Campello, M. (2007) Is cash negative debt? A hedging perspective on corporate financial policies. *Journal of Financial Intermediation* 16(4): 515-554.

Ackert, L.F. and Tian, Y.S. (2000) Arbitrage and valuation in the market for Standard and Poor's Depositary Receipts. *Financial Management* 29(3): 71-87.

Adam, F. and Lin, L.H. (2001) An Analysis of the Applications of Neural Networks in Finance. *Interfaces* 31(4): 112-122.

Adams, Z. and Glück, T. (2015) Financialization in commodity markets: A passing trend or the new normal? *Journal of Banking & Finance* 60: 93-111.

Adrangi, B., Chatrath, A., Song, F. and Szidarovszky, F. (2006) Petroleum spreads and the term structure of futures prices. *Applied Economics* 38(16): 1917-1929.

Adrian, T., Begalle, B., Copeland, A. and Martin, A. (2013) Repo and Securities Lending. *Federal Reserve Bank of New York Staff Reports*, No. 529. Available online:
`https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr529.pdf`.

Adrian, T. and Wu, H. (2010) The Term Structure of Inflation Expectations. *Federal Reserve Bank of New York Staff Reports*, No. 362. Available online: https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr362.pdf.

Agapova, A. (2011a) Conventional mutual funds versus exchange-traded funds. *Journal of Financial Markets* 14(2): 323-343.

Agapova, A. (2011b) The Role of Money Market Mutual Funds in Mutual Fund Families. *Journal of Applied Finance* 21(1): 87-102.

Agarwal, V., Fung, W.H., Loon, Y.C. and Naik, N.Y. (2011) Risk and return in convertible arbitrage: Evidence from the convertible bond market. *Journal of Empirical Finance* 18(2): 175-194.

Ahmadi, H.Z., Sharp, P.A. and Walther, C.H. (1986) The effectiveness of futures and options in hedging currency risk. In: Fabozzi, F. (ed.) *Advances in Futures and Options Research*, Vol. 1, Part B. Greenwich, CT: JAI Press, Inc., pp. 171-191.

Ahmerkamp, J.D. and Grant, J. (2013) The Returns to Carry and Momentum Strategies. *Working Paper.* Available online: https://ssrn.com/abstract=2227387.

Ahn, D.-H., Boudoukh, J., Richardson, M. and Whitelaw, R.F. (2002) Partial adjustment or stale prices? Implications from stock index and futures return autocorrelations. *Review of Financial Studies* 15(2): 655-689.

Ahn, D.-H., Conrad, J. and Dittmar, R. (2003) Risk Adjustment and Trading Strategies. *Review of Financial Studies* 16(2): 459-485.

Ai, H. and Bansal, R. (2016) Risk Preferences and the Macro Announcement Premium. *Working Paper.* Available online: https://ssrn.com/abstract=2827445.

Aiba, Y. and Hatano, N. (2006) A microscopic model of triangular arbitrage. *Physica A: Statistical Mechanics and its Applications* 371(2): 572-584.

Aiba, Y., Hatano, N., Takayasu, H., Marumo, K. and Shimizu, T. (2002) Triangular arbitrage as an interaction among foreign exchange rates. *Physica A: Statistical Mechanics and its Applications* 310(3-4): 467-479.

Aiba, Y., Hatano, N., Takayasu, H., Marumo, K. and Shimizu, T. (2003) Triangular arbitrage and negative auto-correlation of foreign exchange rates. *Physica A: Statistical Mechanics and its Applications* 324(1-2): 253-257.

Äijö, J. (2008) Implied volatility term structure linkages between VDAX, VSMI and VSTOXX volatility indices. *Global Finance Journal* 18(3): 290-302.

Aït-Sahalia, Y. and Duarte, J. (2003) Nonparametric option pricing under shape restrictions. *Journal of Econometrics* 116(1-2): 9-47.

Aït-Sahalia, Y., Karaman, M. and Mancini, L. (2015) The Term Structure of Variance Swaps and Risk Premia. *Working Paper.* Available online: https://ssrn.com/abstract=2136820.

Akram, Q.F., Rime, D. and Sarno, L. (2008) Arbitrage in the foreign exchange market: Turning on the microscope. *Journal of International Economics* 76(2): 237-253.

Alaminos, D., del Castillo, A. and Fernández, M.Á. (2016) A Global Model for Bankruptcy Prediction. *PLoS ONE* 11(11): e0166693.

Alaton, P., Djehiche, B. and Stillberger, D. (2010) On modelling and pricing weather derivatives. *Applied Mathematical Finance* 9(1): 1-20.

Albeverio, S., Steblovskaya, V. and Wallbaum, K. (2013) Investment instruments with volatility target mechanism. *Quantitative Finance* 13(10): 1519-1528.

Albrecht, P. (1985) A note on immunization under a general stochastic equilibrium model of the term structure. *Insurance: Mathematics and Economics* 4(4): 239-244.

Aldohni, A.K. (2013) Loan Sharks v. Short-term Lenders: How Do the Law and Regulators Draw the Line? *Journal of Law and Society* 40(3): 420-449.

Aldridge, I. (2013) *High-Frequency Trading: A Practical Guide to Algorithmic Strategies and Trading Systems.* (2nd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Aldridge, I. (2016) ETFs, High-Frequency Trading, and Flash Crashes. *Journal of Portfolio Management* 43(1): 17-28.

Alessandretti, L., ElBahrawy, A., Aiello, L.M. and Baronchelli, A. (2018) Machine Learning the Cryptocurrency Market. *Working Paper.* Available online: https://arxiv.org/pdf/1805.08550.pdf.

Alexander, C. and Korovilas, D. (2012) Understanding ETNs on VIX Futures. *Working Paper.* Available online: https://ssrn.com/abstract=2043061.

Alexander, G.J. and Resnick, B.G. (1985) Using linear and goal programming to immunize bond portfolios. *Journal of Banking & Finance* 9(1): 35-54.

Allen, F. and Michaely, R. (1995) Dividend Policy. In: Jarrow, R.A., Maksimovic, V. and Ziemba, W.T. (eds.) *Handbooks in Operations Research and Management Science*, Vol 9. Amsterdam, The Netherlands: Elsevier, Chapter 25, pp. 793-837.

Almeida, H., Campello, M. and Weisbach, M.S. (2005) The Cash Flow Sensitivity of Cash. *Journal of Finance* 59(4): 1777-1804.

Almgren, R., Thum, C., Hauptmann, E. and Li, H. (2005) Equity market impact. *Risk Magazine* 18(7): 57-62.

Altman, E.I. (1968) Financial Ratios, Discriminant Analysis and the Prediction of Corporate Bankruptcy. *Journal of Finance* 23(4): 589-609.

Altman, E. (1993) *Corporate financial distress and bankruptcy.* (2nd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Altman, E.I. (1998) Market Dynamics and Investment Performance of Distressed and Defaulted Debt Securities. *Working Paper.* Available online: `https://ssrn.com/abstract=164502`.

Altman, N.S. (1992) An introduction to kernel and nearest-neighbor nonparametric regression. *American Statistician* 46(3): 175-185.

Altman, E.I., Brady, B., Resti, A. and Sironi, A. (2005) The link between default and recovery rates: theory, empirical evidence and implications. *Journal of Business* 78(6): 2203-2228.

Altman, E.I. and Hotchkiss, E. (2006) *Corporate Financial Distress and Bankruptcy: Predict and Avoid Bankruptcy, Analyze and Invest in Distressed Debt.* Hoboken, NJ: John Wiley & Sons, Inc.

Amaitiek, O.F.S., Bálint, T. and Rešovský, M. (2010) The Short Call Ladder strategy and its application in trading and hedging. *Acta Montanistica Slovaca* 15(3): 171-182.

Amato, J.D. and Gyntelberg, J. (2005) CDS Index Tranches and the Pricing of Credit Risk Correlations. *BIS Quarterly Review*, December 2005, pp. 73-87. Available online: `https://www.bis.org/publ/qtrpdf/r_qt0503g.pdf`.

Amato, J.D. and Remolona, E.M. (2003) The credit spread puzzle. *BIS Quarterly Review*, December 2003, pp. 51-63. Available online: `https://www.bis.org/publ/qtrpdf/r_qt0312e.pdf`.

Ambrose, B., LaCour-Little, M. and Sanders, A. (2004) The Effect of Conforming Loan Status on Mortgage Yield Spreads: A Loan Level Analysis. *Real Estate Economics* 32(4): 541-569.

Amenc, N., Ducoulombier, F., Goltz, F. and Ulahel, J. (2016) Ten Misconceptions about Smart Beta. *Working Paper.* Available online: https://www.edhec.edu/sites/www.edhec-portail.pprod.net/files/publications/pdf/edhec-position-paper-ten-misconceptions-about-smart-beta%5F1468395239135-pdfjpg.

Amenc, N., Goltz, F., Sivasubramanian, S. and Lodh, A. (2015) Robustness of Smart Beta Strategies. *Journal of Index Investing* 6(1): 17-38.

Amenc, N., Martellini, L. and Ziemann, V. (2009) Inflation-Hedging Properties of Real Assets and Implications for Asset-Liability Management Decisions. *Journal of Portfolio Management* 35(4): 94-110.

Amihud, Y. (2002) Illiquidity and stock returns: cross-section and time-series effects. *Journal of Financial Markets* 5(1): 31-56.

Amihud, Y. and Goyenko, R. (2013) Mutual Fund's R^2 as Predictor of Performance. *Review of Financial Studies* 26(3): 667-694.

Amihud, Y. and Murgia, M. (1997) Dividends, Taxes, and Signaling: Evidence from Germany. *Journal of Finance* 52(1): 397-408.

Amin, G.S. and Kat, H.M. (2003) Welcome to the Dark Side: Hedge Fund Attrition and Survivorship Bias over the Period 1994-2001. *Journal of Alternative Investments* 6(1): 57-73.

Amiri, M., Zandieh, M., Vahdani, B., Soltani, R. and Roshanaei, V. (2010) An integrated eigenvector-DEA-TOPSIS methodology for portfolio risk evaluation in the FOREX spot market. *Expert Systems with Applications* 37(1): 509-516.

Amjad, M.J. and Shah, D. (2017) Trading Bitcoin and Online Time Series Prediction. *Working Paper.* Available online: http://proceedings.mlr.press/v55/amjad16.pdf.

Ammann, M., Kind, A. and Seiz, R. (2010) What drives the performance of convertible-bond funds? *Journal of Banking & Finance* 34(11): 2600-2613.

Ammann, M., Kind, A. and Wilde, C. (2003) Are convertible bonds underpriced? An analysis of the French market. *Journal of Banking & Finance* 27(4): 635-653.

An, B.-J., Ang, A., Bali, T.G. and Cakici, N. (2014) The Joint Cross Section of Stocks and Options. *Journal of Finance* 69(5): 2279-2337.

Anacker, K.B. (2009) Big flipping schemes in small cities? The case of Mansfield, Ohio. *Housing and Society* 36(1): 5-28.

Anacker, K.B. and Schintler, L.A. (2015) Flip that house: visualising and analysing potential real estate property flipping transactions in a cold local housing market in the United States. *International Journal of Housing Policy* 15(3): 285-303.

Anand, A. and Venkataraman, K. (2016) Market Conditions, Fragility, and the Economics of Market Making. *Journal of Financial Economics* 121(2): 327-349.

Andersen, L. (1999) A Simple Approach to the Pricing of Bermudan Swaptions in the Multi-factor Libor Market Model. *Journal of Computational Finance* 3(2): 5-32.

Andersen, L.B.G. (2010) Markov models for commodity futures: theory and practice. *Quantitative Finance* 10(8): 831-854.

Andersen, L. and Sidenius, J. (2005) Extensions to the Gaussian Copula: Random Recovery and Random Factor Loadings. *Journal of Credit Risk* 1(1): 29-70.

Andersen, L., Sidenius, J. and Basu, S. (2003) All your hedges in one basket. *Risk*, November 2003, pp. 67-72.

Anderson, R.M., Bianchi, S.W. and Goldberg, L.R. (2014) Determinants of Levered Portfolio Performance. *Financial Analysts Journal* 70(5): 53-72.

Anderson, R.W. and Danthine, J.P. (1981) Cross Hedging. *Journal of Political Economy* 89(6): 1182-1196.

Andrade, G., Mitchell, M. and Stafford, E. (2001) New evidence and perspectives on mergers. *Journal of Economic Perspectives* 15(2): 103-120.

Andrieş, A.M. and Vîrlan, C.A. (2017) Risk arbitrage in emerging Europe: are cross-border mergers and acquisition deals more risky? *Economic Research – Ekonomska Istraživanja* 30(1): 1367-1389.

Ané, T. and Labidi, C. (2001) Implied volatility surfaces and market activity over time. *Journal of Economics and Finance* 25(3): 259-275.

Ang, S., Alles, L. and Allen, D. (1998) Riding the Yield Curve: An Analysis of International Evidence. *Journal of Fixed Income* 8(3): 57-74.

Ang, A., Bekaert, G. and Wei, M. (2008) The Term Structure of Real Rates and Expected Inflation. *Journal of Finance* 63(2): 797-849.

Ang, A., Green, R.C., Longstaff, F.A. and Xing, Y. (2017) Advance Refundings of Municipal Bonds. *Journal of Finance* 72(4): 1645-1682.

Ang, A., Hodrick, R., Xing, Y. and Zhang, X. (2006) The Cross-Section of Volatility and Expected Returns. *Journal of Finance* 61(1): 259-299.

Ang, A., Hodrick, R., Xing, Y. and Zhang, X. (2009) High Idiosyncratic Volatility and Low Returns: International and Further U.S. Evidence. *Journal of Financial Economics* 91(1): 1-23.

Ang, K.K. and Quek, C. (2006) Stock trading using RSPOP: A novel rough set-based neuro-fuzzy approach. *IEEE Transactions on Neural Networks* 17(5): 1301-1315.

Anglin, P.M., Rutherford, R. and Springer, T. (2003) The Trade-off Between the Selling Price of Residential Properties and Time-on-the-Market: The Impact of Price Setting. *Journal of Real Estate Finance and Economics* 26(1): 95-111.

Anker, P. (1999) Uncovered interest parity, monetary policy and time-varying risk premia. *Journal of International Money and Finance* 18(6): 835-851.

Ankirchner, S., Dimitroff, G., Heyne, G. and Pigorsch, C. (2012) Futures Cross-Hedging with a Stationary Basis. *Journal of Financial and Quantitative Analysis* 47(6): 1361-1395.

Ankirchner, S. and Heyne, G. (2012) Cross Hedging with Stochastic Correlation. *Finance and Stochastics* 16(1): 17-43.

Ansar, A., Flyvbjerg, B., Budzier, A. and Lunn, D. (2016) Does infrastructure investment lead to economic growth or economic fragility? Evidence from China. *Oxford Review of Economic Policy* 32(3): 360-390.

Anson, M.J.P (1998) Spot Returns, Roll Yield, and Diversification with Commodity Futures. *Journal of Alternative Investments* 1(3): 16-32.

Anson, M. (2013) Performance Measurement in Private Equity: The Impact of FAS 157 on the Lagged Beta Effect. *Journal of Private Equity* 17(1): 29-44.

Antonacci, G. (2014) *Dual Momentum Investing: An Innovative Strategy for Higher Returns with Lower Risk.* New York, NY: McGraw-Hill, Inc.

Antonacci, G. (2017) Risk Premia Harvesting Through Dual Momentum. *Journal of Management & Entrepreneurship* 11(1): 27-55.

Antoniou, A. and Holmes, P. (1995) Futures Trading, Information and Spot Price Volatility: Evidence from the FTSE 100 Stock Index Futures Contract using GARCH. *Journal of Banking & Finance* 19(1): 117-129.

Aragon, G.O., Ergun, A.T., Getmansky, M. and Girardi, G. (2017) Hedge Fund Liquidity Management. *Working Paper.* Available online: https://ssrn.com/abstract=3033930.

Ardizzi, G., Petraglia, C., Piacenza, M., Schneider, F. and Turati, G. (2014) Money Laundering as a Crime in the Financial Sector: A New Approach to Quantitative Assessment, with an Application to Italy. *Journal of Money, Credit and Banking* 46(8): 1555-1590.

Aretz, K. and Pope, P.F. (2013) Common factors in default risk across countries and industries. *European Financial Management* 19(1): 108-152.

Arezki, R. and Sy, A. (2016) Financing Africa's Infrastructure Deficit: From Development Banking to Long-term Investing. *Journal of African Economies* 25(S2): 59-73.

Armann, V. and Weisdorf, M. (2008) Hedging Inflation with Infrastructure Assets. In: Benaben, B. and Goldenberg, S. (eds.) *Inflation Risk and Products: The Complete Guide.* London, UK: Risk Books, pp. 111-126.

Arnott, R., Chaves, D., Gunzberg, J., Hsu, J. and Tsui, P. (2014) Getting Smarter about Commodities: An index to counter the possible pitfalls. *Journal of Indexes*, November/December 2014, pp. 52-60.

Arnott, R.D., Hsu, J., Kalesnik, V. and Tindall, P. (2013) The Surprising Alpha from Malkiel's Monkey and Upside-Down Strategies. *Journal of Portfolio Management* 39(4): 91-105.

Arnsdorf, M. and Halperin, I. (2007) BSLP: Markovian bivariate spread-loss model for portfolio credit derivatives. *Working Paper.* Available online: https://arxiv.org/pdf/0901.3398.

Asem, E. and Tian, G. (2010) Market Dynamics and Momentum Profits. *Journal of Financial and Quantitative Analysis* 45(6): 1549-1562.

Asgharian, M., Diz, F., Gregoriou, G.N. and Rouah, F. (2004) The Global Macro Hedge Fund Cemetery. *Journal of Derivatives Accounting* 1(2): 187-194.

Asgharian, H. and Karlsson, S. (2008) An Empirical Analysis of Factors Driving the Swap Spread. *Journal of Fixed Income* 18(2): 41-56.

Asness, C.S. (1994) *Variables that Explain Stock Returns* (Ph.D. Thesis). Chicago, IL: University of Chicago.

Asness, C.S. (1995) The Power of Past Stock Returns to Explain Future Stock Returns. *Working Paper* (unpublished). New York, NY: Goldman Sachs Asset Management.

Asness, C. (1997) The Interaction of Value and Momentum Strategies. *Financial Analysts Journal* 53(2): 29-36.

Asness, C., Frazzini, A., Israel, R. and Moskowitz, T. (2014) Fact, Fiction, and Momentum Investing. *Journal of Portfolio Management* 40(5): 75-92.

Asness, C., Krail, R.J. and Liew, J.M. (2001) Do Hedge Funds Hedge? *Journal of Portfolio Management* 28(1): 6-19.

Asness, C., Moskowitz, T. and Pedersen, L.H. (2013) Value and Momentum Everywhere. *Journal of Finance* 68(3): 929-985.

Asness, C.S., Porter, R.B. and Stevens, R.L. (2000) Predicting Stock Returns Using Industry-Relative Firm Characteristics. *Working Paper.* Available online: `https://ssrn.com/abstract=213872`.

Augustin, P., Brenner, B. and Subrahmanyam, M.G. (2015) Informed Options Trading prior to M&A Announcements: Insider Trading? *Working Paper.* Available online: `https://ssrn.com/abstract=2441606`.

Aussenegg, W., Götz, L. and Jelic, R. (2014) European asset swap spreads and the credit crisis. *European Journal of Finance* 22(7): 572-600.

Avdjiev, S., Du, W., Koch, C. and Shin, H.S. (2016) The Dollar, Bank Leverage and the Deviation from Covered Interest Parity. *Working Paper.* Available online: `https://ssrn.com/abstract=2870057`.

Avellaneda, M. and Lee, J.H. (2010) Statistical arbitrage in the U.S. equity market. *Quantitative Finance* 10(7): 761-782.

Avellaneda, M. and Papanicolaou, A. (2018) Statistics of VIX Futures and Applications to Trading Volatility Exchange-Traded Products. *Journal of Investment Strategies* 7(2): 1-33.

Avellaneda, M. and Stoikov, S. (2008) High frequency trading in a limit order book. *Quantitative Finance* 8(3): 217-224.

Avellaneda, M. and Zhang, S. (2010) Path-Dependence of Leveraged ETF Returns. *Journal on Financial Mathematics* 1(1): 586-603.

Ayache, E., Forsyth, P.A. and Vetzal, K.R. (2003) Valuation of Convertible Bonds With Credit Risk. *Journal of Derivatives* 11(1): 9-29.

Ayuso, J. and Restoy, F. (1996) Interest Rate Parity and Foreign Exchange Risk Premia in the ERM. *Journal of International Money and Finance* 15(3): 369-382.

Azmat, Q. and Iqbal, A.M. (2017) The role of financial constraints on precautionary cash holdings: evidence from Pakistan. *Economic Research – Ekonomska Istraživanja* 30(1): 596-610.

Baba, N. and Packer, F. (2009) Interpreting deviations from covered interest parity during the financial market turmoil of 2007-08. *Journal of Banking & Finance* 33(11): 1953-1962.

Babbs, S.H. and Nowman, B.K. (1999) Kalman filtering of generalized Vasicek term structure models. *Journal of Financial and Quantitative Analysis* 34(1): 115-130.

Bacchetta, P. and van Wincoop, E. (2006) Incomplete Information Processing: A Solution to the Forward Discount Puzzle. *American Economic Review* 96(3): 552-576.

Bacchetta, P. and van Wincoop, E. (2010) Infrequent Portfolio Decisions: A Solution to the Forward Discount Puzzle. *American Economic Review* 100(3): 870-904.

Baek, C. and Elbeck, M. (2014) Bitcoins as an Investment or Speculative Vehicle? A First Look. *Applied Economics Letters* 22(1): 30-34.

Bai, Q., Bond, S.A. and Hatch, B.C. (2015) The Impact of Leveraged and Inverse ETFs on Underlying Real Estate Returns. *Real Estate Economics* 43(1): 37-66.

Bai, J. and Collin-Dufresne, P. (2013) The CDS-Bond Basis. *Working Paper.* Available online: `https://ssrn.com/abstract=2024531`.

Baillie, R.T. and Myers, R.J. (1991) Bivariate GARCH estimation of the optimal commodity futures hedge. *Journal of Applied Econometrics* 6(2): 109-124.

Baillie, R.T. and Osterberg, W.P. (2000) Deviations from daily uncovered interest rate parity and the role of intervention. *Journal of International Financial Markets, Institutions and Money* 10(4): 363-379.

Baker, M., Bradley, B. and Wurgler, J. (2011) Benchmarks as Limits to Arbitrage: Understanding the Low-Volatility Anomaly. *Financial Analysts Journal* 67(1): 40-54.

Baker, M., Pan, A. and Wurgler, J. (2012) The effect of reference point prices on mergers and acquisitions. *Journal of Financial Economics* 106(1): 49-71.

Baker, M. and Savaşoglu, S. (2002) Limited arbitrage in mergers and acquisitions. *Journal of Financial Economics* 64(1): 91-115.

Bakshi, G. and Kapadia, N. (2003a) Delta-Hedged Gains and the Negative Market Volatility Risk Premium. *Review of Financial Studies* 16(2): 527-566.

Bakshi, G. and Kapadia, N. (2003b) Volatility Risk Premiums Embedded in Individual Equity Options. *Journal of Derivatives* 11(1): 45-54.

Bakshi, G., Kapadia, N. and Madan, D. (2003) Stock Return Characteristics, Skew Laws, and the Differential Pricing of Individual Equity Options. *Review of Financial Studies* 16(1): 101-143.

Bakshi, G. and Panayotov, G. (2013) Predictability of currency carry trades and asset pricing implications. *Journal of Financial Economics* 110(1): 139-163.

Balbás, A., Longarela, I.R. and Lucia, J.J. (1999) How Financial Theory Applies to Catastrophe-Linked Derivatives – An Empirical Test of Several Pricing Models. *Journal of Risk and Insurance* 66(4): 551-582.

Bali, T.G. and Demirtas, K.O. (2008) Testing mean reversion in financial market volatility: Evidence from S&P 500 index futures. *Journal of Futures Markets* 28(1): 1-33.

Bali, T.G. and Hovakimian, A. (2009) Volatility Spreads and Expected Stock Returns. *Management Science* 55(11): 1797-1812.

Ballings, M., Van den Poel, D., Hespeels, N. and Gryp, R. (2015) Evaluating multiple classifiers for stock price direction prediction. *Expert Systems with Applications* 42(20): 7046-7056.

Balta, A.-N. and Kosowki, R. (2013) Momentum Strategies in Futures Markets and Trend-Following Funds. *Working Paper.* Available online: `https://www.edhec.edu/sites/www.edhec-portail.pprod.net/files/publications/pdf/edhec-working-paper-momentum-strategies-in-futures_1410350911195-pdfjpg`.

Bandarchuk, P. and Hilscher, J. (2013) Sources of Momentum Profits: Evidence on the Irrelevance of Characteristics. *Review of Finance* 17(2): 809-845.

Banz, R. (1981) The relationship between return and market value of common stocks. *Journal of Financial Economics* 9(1): 3-18.

Barber, J., Bennett, S. and Gvozdeva, E. (2015) How to Choose a Strategic Multifactor Equity Portfolio? *Journal of Index Investing* 6(2): 34-45.

Barberis, N. (2000) Investing for the Long Run when Returns Are Predictable. *Journal of Finance* 55(1): 225-264.

Barberis, N. and Huang, M. (2008) Stocks as Lotteries: The Implications of Probability Weighting for Security Prices. *American Economic Review* 98(5): 2066-2100.

Bardong, F. and Lehnert, T. (2004) TIPS, Break-Even Inflation, and Inflation Forecasts. *Journal of Fixed Income* 14(3): 15-35.

Bariviera, A.F., Basgall, M.J., Hasperué, W. and Naiouf, M. (2017) Some stylized facts of the Bitcoin market. *Physica A: Statistical Mechanics and its Applications* 484: 82-90.

Barnes, M.L., Bodie, Z., Triest, R.K. and Wang, J.C. (2010) A TIPS Scorecard: Are They Accomplishing Their Objectives? *Financial Analysts Journal* 66(5): 68-84.

Baron, M., Brogaard, J., Hagströmer, B. and Kirilenko, A. (2014) Risk and Return in High-Frequency Trading. *Journal of Financial and Quantitative Analysis* (forthcoming). Available online: `https://ssrn.com/abstract=2433118`.

Barr, D.G. and Campbell, J.Y. (1997) Inflation, real interest rates, and the bond market: A study of UK nominal and index-linked government bond prices. *Journal of Monetary Economics* 39(3): 361-383.

Barrett, W.B. and Kolb, R.W. (1995) Analysis of spreads in agricultural futures. *Journal of Futures Markets* 15(1): 69-86.

Barrieu, P. and El Karoui, N. (2002) Optimal design of weather derivatives. *ALGO Research* 5(1): 79-92.

Barrieu, P. and Scaillet, O. (2010) A Primer on Weather Derivatives. In: Filar, J.A. and Haurie, A. (eds.) *Uncertainty and Environmental Decision Making: A Handbook of Research and Best Practice.* International Series in Operations Research & Management Science, Vol. 138. New York, NY: Springer U.S.

Barroso, P. and Santa-Clara, P. (2014) Momentum Has Its Moments. *Journal of Financial Economics* 116(1): 111-120.

Bartonová, M. (2012) Hedging of Sales by Zero-cost Collar and its Financial Impact. *Journal of Competitiveness* 4(2): 111-127.

Bartov, E., Radhakrishnan, S. and Krinsky, I. (2005) Investor Sophistication and Patterns in Stock Returns after Earnings Announcements. *Accounting Review* 75(1): 289-319.

Basu, S. (1977) The investment performance of common stocks in relation to their price to earnings ratios: A test of the efficient market hypothesis. *Journal of Finance* 32(3): 663-682.

Basu, D. and Miffre, J. (2013) Capturing the risk premium of commodity futures: The role of hedging pressure. *Journal of Banking & Finance* 37(7): 2652-2664.

Batta, G., Chacko, G. and Dharan, B. (2010) A Liquidity-Based Explanation of Convertible Arbitrage Alphas. *Journal of Fixed Income* 20(1): 28-43.

Battalio, R. and Mendenhall, R. (2007) Post-Earnings Announcement Drift: Intra-Day Timing and Liquidity Costs. *Working Paper.* Available online: https://ssrn.com/abstract=937257.

Batten, J. and Ellis, C. (1996) Technical trading system performance in the Australian share market: Some empirical evidence. *Asia Pacific Journal of Management* 13(1): 87-99.

Batten, J.A., Khaw, K. and Young, M.R. (2014) Convertible Bond Pricing Models. *Journal of Economic Surveys* 28(5): 775-803.

Baxter, M. and King, R. (1999) Measuring business cycles: Approximate band-pass filters for economic time-series. *Review of Economics and Statistics* 81(4): 575-593.

Baxter, M. and Rennie, A. (1996) *Financial Calculus: An Introduction to Derivative Pricing.* Cambridge, UK: Cambridge University Press.

Bayer, P.J., Geissler, C., Mangum, K. and Roberts, J.W. (2015) Speculators and Middlemen: The Strategy and Performance of Investors in the Housing Market. *Working Paper.* Available online: https://ssrn.com/abstract=1754003.

Beaver, W.H. (1966) Financial ratios as predictors of failure. *Journal of Accounting Research* 4: 71-111.

Beaver, W.H., McNichols, M.F. and Rhie, J.-W. (2005) Have financial statements become less informative? Evidence from the ability of financial ratios to predict bankruptcy. *Review of Accounting Studies* 10(1): 93-122.

Bedendo, M., Cathcart, L. and El-Jahel, L. (2007) The Slope of the Term Structure of Credit Spreads: An Empirical Investigation. *Journal of Financial Research* 30(2): 237-257.

Beekhuizen, P., Duyvesteyn, J., Martens, M. and Zomerdijk, C. (2016) Carry Investing on the Yield Curve. *Working Paper.* Available online: http://ssrn.com/abstract=2808327.

Bekaert, G. and Wang, X. (2010) Inflation Risk and the Inflation Risk Premium. *Economic Policy* 25(64): 755-806.

Bekaert, G., Wei, M. and Xing, Y. (2007) Uncovered interest rate parity and the term structure. *Journal of International Money and Finance* 26(6): 1038-1069.

Bekkers, N., Doeswijk, R.Q. and Lam, T.W. (2009) Strategic Asset Allocation: Determining the Optimal Portfolio with Ten Asset Classes. *Journal of Wealth Management* 12(3): 61-77.

Belgrade, N. and Benhamou, E. (2004) Reconciling Year on Year and Zero Coupon Inflation Swap: A Market Model Approach. *Working Paper.* Available online: `https://ssrn.com/abstract=583641`.

Belgrade, N., Benhamou, E. and Koehler, E. (2004) A Market Model for Inflation. *Working Paper.* Available online: `https://ssrn.com/abstract=576081`.

Belkin, B., Suchover, S. and Forest, L. (1998) A one-parameter representation of credit risk and transition matrices. *Credit Metrics Monitor* 1(3): 46-56.

Bellamy, D.E. (1994) Evidence of imputation clienteles in the Australian equity market. *Asia Pacific Journal of Management* 11(2): 275-287.

Bellovary, J.L., Giacomino, D.E. and Akers, M.D. (2007) A review of bankruptcy prediction studies: 1930 to present. *Journal of Financial Education* 33(4): 3-41.

Benavides, G. (2009) Predictive Accuracy of Futures Options Implied Volatility: The Case of the Exchange Rate Futures Mexican Peso-US Dollar. *Panorama Económico* 5(9): 55-95.

Ben-David, I., Franzoni, F.A. and Moussawi, R. (2012) ETFs, Arbitrage, and Contagion. *Working Paper.* Available online: `http://www.nccr-finrisk.uzh.ch/media/pdf/wp/WP793_B1.pdf`.

Ben-David, I., Franzoni, F.A. and Moussawi, R. (2017) Do ETFs Increase Volatility? *Journal of Finance* (forthcoming). Available online: `https://ssrn.com/abstract=1967599`.

Beneish, M.D. and Whaley, R.E. (1996) An Anatomy of the "S&P Game": The Effects of Changing the Rules. *Journal of Finance* 51(5): 1909-1930.

Benet, B.A. (1990) Commodity futures cross hedging of foreign exchange exposure. *Journal of Futures Markets* 10(3): 287-306.

Bengio, Y. (2009) Learning Deep Architectures for AI. *Foundations and Trends in Machine Learning* 2(1): 1-127.

Benhamou, E. (2016) Trend Without Hiccups – A Kalman Filter Approach. *Working Paper.* Available online: https://ssrn.com/abstract=2747102.

Benos, E., Brugler, J., Hjalmarsson, E. and Zikes, F. (2017) Interactions among High-Frequency Traders. *Journal of Financial and Quantitative Analysis* 52(4): 1375-1402.

Benos, E. and Sagade, S. (2016) Price Discovery and the Cross-Section of High-Frequency Trading. *Journal of Financial Markets* 30: 54-77.

Benth, F. (2003) On arbitrage-free pricing of weather derivatives based on fractional Brownian motion. *Applied Mathematical Finance* 10(4): 303-324.

Benth, F.E. and Kettler, P.C. (2010) Dynamic copula models for the spark spread. *Quantitative Finance* 11(3): 407-421.

Benth, F.E., Kholodnyi, V.A. and Laurence, P. (eds.) (2014) *Quantitative Energy Finance: Modeling, Pricing, and Hedging in Energy and Commodity Markets.* New York, NY: Springer-Verlag.

Benth, F.E. and Saltyte-Benth, J. (2005) Stochastic modelling of temperature variations with a view towards weather derivatives. *Applied Mathematical Finance* 12(1): 53-85.

Benth, F.E. and Saltyte-Benth, J. (2007) The volatility of temperature and pricing of weather derivatives. *Quantitative Finance* 7(5): 553-561.

Benth, F., Saltyte-Benth, J. and Koekebakker, S. (2007) Putting a price on temperature. *Scandinavian Journal of Statistics* 34(4): 746-767.

BenZion, U., Anan, S.D. and Yagil, J. (2005) Box Spread Strategies and Arbitrage Opportunities. *Journal of Derivatives* 12(3): 47-62.

BenZion, U., Klein, P., Shachmurove, Y. and Yagil, J. (2003) Efficiency differences between the S&P 500 and the Tel-Aviv 25 indices: a moving average comparison. *International Journal of Business* 8(3): 267-284.

Beracha, E. and Downs, D.H. (2015) Value and Momentum in Commercial Real Estate: A Market-Level Analysis. *Journal of Portfolio Management* 41(6): 48-61.

Beracha, E. and Skiba, H. (2011) Momentum in Residential Real Estate. *Journal of Real Estate Finance and Economics* 43(3): 229-320.

Berk, J., Green, R. and Naik, V. (1999) Optimal Investment, Growth Options and Security Returns. *Journal of Finance* 54(5): 1153-1608.

Bernadell, C., Coche, J. and Nyholm, K. (2005) Yield curve prediction for the strategic investor. *Working Paper Series*, No. 472. Frankfurt am Main, Germany: European Central Bank. Available online: `https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp472.pdf?1dc8846d9df4642959c54aa73cee81ad`.

Bernanke, B.S. and Kuttner, K.N. (2005) What Explains the Stock Market's Reaction to Federal Reserve Policy? *Journal of Finance* 60(3): 1221-1257.

Bernard, C., Cui, Z. and Mcleish, D. (2014) Convergence of the discrete variance swap in time-homogeneous diffusion models. *Quantitative Finance Letters* 2(1): 1-6.

Bernard, V.L. and Thomas, J.K. (1989) Post-Earnings-Announcement Drift: Delayed Price Response or Risk Premium? *Journal of Accounting Research* 27: 1-36.

Bernard, V.L. and Thomas, J.K. (1990) Evidence That Stock Prices Do Not Fully Reflect the Implications of Current Earnings for Future Earnings. *Journal of Accounting and Economics* 13(4): 305-340.

Bernardi, S., Leippold, M. and Lohre, H. (2018) Maximum Diversification Strategies along Commodity Risk Factors. *European Financial Management* 24(1): 53-78.

Bernstein, J. (1990) *Jake Bernstein's seasonal futures spreads: high-probability seasonal spreads for futures traders.* Hoboken, NJ: John Wiley & Sons, Inc.

Bessembinder, H. (1992) Systematic risk, hedging pressure, and risk premiums in futures markets. *Review of Financial Studies* 5(4): 637-667.

Bessembinder, H. (1993) An empirical analysis of risk premia in futures markets. *Journal of Futures Markets* 13(6): 611-630.

Bessembinder, H. and Chan, K. (1992) Time-varying risk premia and forecastable returns in futures markets. *Journal of Financial Economics* 32(2): 169-193.

Bessembinder, H., Coughenour, J.F., Seguin, P.J. and Smoller, M.M. (1995) Mean reversion in equilibrium asset prices: evidence from the futures term structure. *Journal of Finance* 50(1): 361-375.

Bessembinder, H. and Maxwell, W. (2008) Markets: Transparency and the Corporate Bond Market. *Journal of Economic Perspectives* 22(2): 217-234.

Bessembinder, H. and Seguin, P.J. (1993) Price volatility, trading volume, and market depth: Evidence from futures markets. *Journal of Financial and Quantitative Analysis* 28(1): 21-39.

Bester, A., Martinez, V.H. and Rosu, I. (2017) Cash Mergers and the Volatility Smile. *Working Paper.* Available online: https://ssrn.com/abstract=1364491.

Beyaert, A., García-Solanes, J. and Pérez-Castejón, J.J. (2007) Uncovered interest parity with switching regimes. *Economic Modelling* 24(2): 189-202.

Bharadwaj, A. and Wiggins, J.B. (2001) Box Spread and Put-Call Parity Tests for the S&P 500 Index LEAPS Market. *Journal of Derivatives* 8(4): 62-71.

Bhattacharya, U., Loos, B., Meyer, S. and Hackethal, A. (2017) Abusing ETFs. *Review of Finance* 21(3): 1217-1250.

Bhojraj, S. and Swaminathan, B. (2006) Macromomentum: Returns Predictability in International Equity Indices. *Journal of Business* 79(1): 429-451.

Bhushan, R. (1994) An Informational Efficiency Perspective on the Post-Earnings Announcement Drift. *Journal of Accounting and Economics* 18(1): 45-65.

Biais, B. and Foucault, T. (2014) HFT and market quality. *Bankers, Markets & Investors* 128: 5-19.

Biais, B., Foucault, T. and Moinas, S. (2014) Equilibrium Fast Trading. *Working Paper.* Available online: https://ssrn.com/abstract=2024360.

Bianchi, R.J., Drew, M. and Fan, J. (2015) Combining momentum with reversal in commodity futures. *Journal of Banking & Finance* 59: 423-444.

Biby, J.D., Modukuri, S. and Hargrave, B. (2001) Collateralized Borrowing via Dollar Rolls. In: Fabozzi, F.J. (ed.) *The Handbook of Mortgage-Backed Securities.* (5th ed.) New York, NY: McGraw-Hill, Inc.

Bielecki, T.R., Brigo, D. and Patras, F. (2011) *Credit Risk Frontiers: Subprime Crisis, Pricing and Hedging, CVA, MBS, Ratings, and Liquidity.* Hoboken, NJ: John Wiley & Sons, Inc.

Bielecki, T., Jeanblanc, M. and Rutkowski, M. (2007) Hedging of basket credit derivatives in the Credit Default Swap market. *Journal of Credit Risk* 3(1): 91-132.

Bielecki, T., Vidozzi, A. and Vidozzi, L. (2008) A Markov copulae approach to pricing and hedging of credit index derivatives and ratings triggered step-up bonds. *Journal of Credit Risk* 4(1): 47-76.

Bieri, D.S. and Chincarini, L.B. (2004) Riding the Yield Curve: Diversification of Strategies. *Working Paper.* Available online: https://ssrn.com/abstract=547682.

Bieri, D.S. and Chincarini, L.B. (2005) Riding the Yield Curve: A Variety of Strategies. *Journal of Fixed Income* 15(2): 6-35.

Bierwag, G.O. (1979) Dynamic portfolio immunization policies. *Journal of Banking & Finance* 3(1): 23-41.

Bierwag, G.O. and Kaufman, G. (1978) Bond Portfolio Strategy Simulations: A Critique. *Journal of Financial and Quantitative Analysis* 13(3): 519-525.

Billingsley, R.S. and Chance, D.M. (1985) Options Market Efficiency and the Box Spread Strategy. *Financial Review* 20(4): 287-301.

Billingsley, R.S. and Chance, D.M. (1988) The pricing and performance of stock index futures spreads. *Journal of Futures Markets* 8(3): 303-318.

Bilson, J.F.O. (1981) The "Speculative Efficiency" Hypothesis. *Journal of Business* 54(3): 435-451.

Birari, A. and Rode, M. (2014) Edge Ratio of Nifty for Last 15 Years on Donchian Channel. *SIJ Transactions on Industrial, Financial & Business Management (IFBM)* 2(5): 247-254.

Bird, R., Liem, H. and Thorp, S. (2014) Infrastructure: Real Assets and Real Returns. *European Financial Management* 20(4): 802-824.

Bitsch, F., Buchner, A. and Kaserer, C. (2010) Risk, Return and Cash Flow Characteristics of Infrastructure Fund Investments. *EIB Papers* 15(1): 106-136.

Bjornson, B. and Carter, C.A. (1997) New Evidence on Agricultural Commodity Return Performance under Time-Varying Risk. *American Journal of Agricultural Economics* 79(3): 918-930.

Black, F. (1972) Capital Market Equilibrium with Restricted Borrowing. *Journal of Business* 45(3): 444-455.

Black, F. and Litterman, R. (1991) Asset allocation: Combining investors' views with market equilibrium. *Journal of Fixed Income* 1(2): 7-18.

Black, F. and Litterman, R. (1992) Global portfolio optimization. *Financial Analysts Journal* 48(5): 28-43.

Black, F. and Scholes, M. (1973) The pricing of options and corporate liabilities. *Journal of Political Economy* 81(3): 637-659.

Blake, M.L. and Catlett, L. (1984) Cross Hedging Hay Using Corn Futures: An Empirical Test. *Western Journal of Agricultural Economics* 9(1): 127-134.

Blanc-Brude, F., Hasan, M. and Whittaker, T. (2016) Benchmarking infrastructure project finance: Objectives, roadmap, and recent progress. *Journal of Alternative Investments* 19(2): 7-18.

Blanc-Brude, F., Whittaker, T. and Wilde, S. (2017) Searching for a listed infrastructure asset class using mean-variance spanning. *Financial Markets and Portfolio Management* 31(2): 137-179.

Blanchard, O.J. and Gali, J. (2007) The Macroeconomic Effects of Oil Shocks: Why are the 2000s So Different from the 1970s? *Working Paper.* Available online: http://www.nber.org/papers/w13368.pdf.

Blanchard, O.J. and Riggi, M. (2013) Why are the 2000s so different from the 1970s? A structural interpretation of changes in the macroeconomic effects of oil prices. *Journal of the European Economic Association* 11(5): 1032-1052.

Blank, S.C. (1984) Cross Hedging Australian Cattle. *Australian Journal of Agricultural Economics* 28(2-3): 153-162.

Blitz, D., Huij, J., Lansdorp, S. and Verbeek, M. (2013) Short-term residual reversal. *Journal of Financial Markets* 16(3): 477-504.

Blitz, D., Huij, J. and Martens, M. (2011) Residual Momentum. *Journal of Empirical Finance* 18(3): 506-521.

Blitz, D.C. and van Vliet, P. (2007) The Volatility Effect: Lower Risk without Lower Return. *Journal of Portfolio Management* 34(1): 102-113.

Blitz, D. and Van Vliet, P. (2008) Global Tactical Cross Asset Allocation: Applying Value and Momentum Across Asset Classes. *Journal of Portfolio Management* 35(1): 23-28.

Block, R.L. (2011) *Investing in REITs: Real Estate Investment Trusts.* New York, NY: Bloomberg Press.

Bloesch, J. and Gourio, F. (2015) The effect of winter weather on U.S. economic activity. *Federal Reserve Bank of Chicago, Economic Perspectives* 39(1): 1-20.

Bloom, L., Easley, D. and O'Hara, M. (1994) Market Statistics and Technical Analysis: The Role of Volume. *Journal of Finance* 49(1): 153-181.

Blundell, L. (2006) Infrastructure investment: On the up. *Property Australia* 20(9): 20-22.

Bobey, B. (2010) The Effects of Default Correlation on Corporate Bond Credit Spreads. *Working Paper.* Available online: https://ssrn.com/abstract=1510170.

Bodie, Z. (1983) Commodity Futures as a Hedge against Inflation. *Journal of Portfolio Management* 9(3): 12-17.

Bodie, Z., Kane, A. and Marcus, A.J. (1996) *Investments.* New York, NY: McGraw-Hill, Inc.

Bodie, Z. and Rosansky, V.I. (1980) Risk and Return in Commodity Futures. *Financial Analysts Journal* 36(3): 27-39.

Bogomolov, T. (2013) Pairs trading based on statistical variability of the spread process. *Quantitative Finance* 13(9): 1411-1430.

Bohlin, S. and Strickland, G. (2004) Climbing the Ladder: How to Manage Risk in Your Bond Portfolio. *American Association of Individual Investors Journal*, July 2004, pp. 5-8.

Bol, G., Rachev, S.T. and Würth, R. (eds.) (2009) *Risk Assessment: Decisions in Banking and Finance.* Heidelberg, Germany: Physica-Verlag.

Bollen, N.P.B. and Busse, J.A. (2005) Short-Term Persistence in Mutual Fund Performance. *Review of Financial Studies* 18(2): 569-597.

Bollen, J. and Mao, H. (2011) Twitter mood as a stock market predictor. *Computer* 44(10): 91-94.

Bollen, J., Mao, H. and Zeng, X. (2011) Twitter mood predicts the stock market. *Journal of Computational Science* 2(1): 1-8.

Bollen, N.P.B. and Whaley, R. (2004) Does Net Buying Pressure Affect the Shape of Implied Volatility Functions? *Journal of Finance* 59(2): 711-754.

Bollerslev, T., Gibson, M. and Zhou, H. (2011) Dynamic estimation of volatility risk premia and investor risk aversion from option-implied and realized volatilities. *Journal of Econometrics* 160(1): 235-245.

Bologna, P. and Cavallo, L. (2002) Does the Introduction of Index Futures Effectively Reduce Stock Market Volatility? Is the Futures Effect Immediate? Evidence from the Italian Stock Exchange Using GARCH. *Applied Financial Economics* 12(3): 183-192.

Bond, M.T. and Seiler, M.J. (1998) Real Estate Returns and Inflation: An Added Variable Approach. *Journal of Real Estate Research* 15(3): 327-338.

Bondarenko, O. (2014) Why Are Put Options So Expensive? *Quarterly Journal of Finance* 4(3): 1450015.

Booth, L.D. (1987) The dividend tax credit and Canadian ownership objectives. *Canadian Journal of Economics* 20(2): 321-339.

Booth, L.D. and Johnston, D.J. (1984) The ex-dividend day behavior of Canadian stock prices: Tax changes and clientele effects. *Journal of Finance* 39(2): 457-476.

Booth, J.R., Smith, R.L. and Stolz, R.W. (1984) The Use of Interest Rate Futures by Financial Institutions. *Journal of Bank Research* 15(1): 15-20.

Borovkova, S. and Geman, H. (2006) Seasonal and stochastic effects in commodity forward curves. *Review of Derivatives Research* 9(2): 167-186.

Bos, R. (2000) *Index Calculation Primer.* New York, NY: Standard and Poor's Quantitative Services.

Bos, M., Carter, S. and Skiba, P.M. (2012) The Pawn Industry and Its Customers: The United States and Europe. *Working Paper.* Available online: `https://ssrn.com/abstract=2149575`.

Boscher, H. and Ward, I. (2002) Long or short in CDOs. *Risk*, June 2002, pp. 125-129.

Bossu, S. (2006) Introduction to Variance Swaps. *Wilmott Magazine*, March 2006, pp. 50-55.

Boudoukh, J., Richardson, M. and Whitelaw, R.F. (1994) Industry Returns and the Fisher Effect. *Journal of Finance* 49(5): 1595-1615.

Boudoukh, J., Whitelaw, R., Richardson, M. and Stanton, R. (1997) Pricing Mortgage-Backed Securities in a Multifactor Interest Rate Environment: A Multivariate Density Estimation Approach. *Review of Financial Studies* 10(2): 405-446.

Boulos, N. and Swanson, P.E. (1994) Interest Rate Parity in Times of Turbulence: The Issue Revisited. *Journal of Financial and Strategic Decisions* 7(2): 43-52.

Bouman, F.J.A. and Houtman, R. (1988) Pawnbroking as an Instrument of Rural Banking in the Third World. *Economic Development and Cultural Change* 37(1): 69-89.

Bouoiyour, J., Selmi, R. and Tiwari, A.K. (2015) Is Bitcoin business income or speculative foolery? New ideas through an improved frequency domain analysis. *Annals of Financial Economics* 10(1): 1-23.

Bouoiyour, J., Selmi, R., Tiwari, A.K. and Olayeni, O.R. (2016) What drives Bitcoin price? *Economics Bulletin* 36(2): 843-850.

Bouri, E., Gupta, R., Tiwari, A.K. and Roubaud, D. (2017a) Does Bitcoin hedge global uncertainty? Evidence from wavelet-based quantile-in-quantile regressions. *Finance Research Letters* 23: 87-95.

Bouri, E., Molnár, P., Azzi, G., Roubaud, D. and Hagfors, L.I. (2017b) On the hedge and safe haven properties of Bitcoin: Is it really more than a diversifier? *Finance Research Letters* 20: 192-198.

Bouzoubaa, M. and Osseiran, A. (2010) *Exotic options and hybrids: a Guide to Structuring, Pricing and Trading.* Chichester, UK: John Wiley & Sons, Ltd.

Bowen, D.A. and Hutchinson, M.C. (2016) Pairs trading in the UK equity market: Risk and return. *European Journal of Finance* 22(14): 1363-1387.

Bowen, D., Hutchinson, M.C. and O'Sullivan, N. (2010) High frequency equity pairs trading: Transaction costs, speed of execution and patterns in returns. *Journal of Trading* 5(3): 31-38.

Bowsher, N. (1979) Repurchase Agreements. *Federal Reserve Bank of St. Louis Review* 61(9): 17-22.

Boyarchenko, N., Fuster, A. and Lucca, D.O. (2014) Understanding Mortgage Spreads. *Federal Reserve Bank of New York Staff Reports*, No. 674. Available online:
`https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr674.pdf`.

Boyd, J.H., Hu, J. and Jagannathan, R. (2005) The Stock Market's Reaction to Unemployment News: Why Bad News Is Usually Good for Stocks. *Journal of Finance* 60(2): 649-672.

Boyd, N.E. and Mercer, J.M. (2010) Gains from Active Bond Portfolio Management Strategies. *Journal of Fixed Income* 19(4): 73-83.

Boyle, P.P. (1978) Immunization under stochastic models of the term structure. *Journal of the Institute of Actuaries* 105(2): 177-187.

Bozdog, D., Florescu, I., Khashanah, K. and Wang, J. (2011) Rare Events Analysis of High-Frequency Equity Data. *Wilmott Magazine* 2011(54): 74-81.

Bozic, M. and Fortenbery, T.R. (2012) Creating Synthetic Cheese Futures: A Method for Matching Cash and Futures Prices in Dairy. *Journal of Agribusiness* 30(2): 87-102.

Brandvold, M., Molnár, P., Vagstad, K. and Valstad, O.C.A. (2015) Price discovery on Bitcoin exchanges. *Journal of International Financial Markets, Institutions and Money* 36: 18-35.

Branger, N. and Schlag, C. (2004) Why is the Index Smile So Steep? *Review of Finance* 8(1): 109-127.

Brazil, A.J. (1988) Citicorp's mortgage valuation model: Option-adjusted spreads and option-based durations. *Journal of Real Estate Finance and Economics* 1(2): 151-162.

Breeden, D.T. and Litzenberger, R.H. (1978) Prices of state-contingent claims implicit in option prices. *Journal of Business* 51(4): 621-651.

Brennan, M.J. and Schwartz, E.S. (1977) Convertible Bonds: Valuation and Optimal Strategies for Call and Conversion. *Journal of Finance* 32(5): 1699-1715.

Brennan, M.J. and Schwartz, E.S. (1985) Determinants of GNMA Mortgage Prices. *Real Estate Economics* 13(3): 209-228.

Brennan, M.J. and Schwartz, E.S. (1988) The case for convertibles. *Journal of Applied Corporate Finance* 1(2): 55-64.

Brenner, M., Subrahmanyam, M.G. and Uno, J. (1989) Stock index futures arbitrage in the Japanese markets. *Japan and the World Economy* 1(3): 303-330.

Brezigar-Masten, A. and Masten, P. (2012) CART-based selection of bankruptcy predictors for the logit model. *Expert Systems with Applications* 39(11): 10153-10159.

Brière, M., Oosterlinck, K. and Szafarz, A. (2015) Virtual currency, tangible return: Portfolio diversification with bitcoin. *Journal of Asset Management* 16(6): 365-373.

Briys, E. and Solnik, B. (1992) Optimal currency hedge ratios and interest rate risk. *Journal of International Money and Finance* 11(5): 431-445.

Broadie, M. and Jain, A. (2008) The effect of jumps and discrete sampling on volatility and variance swaps. *International Journal of Theoretical and Applied Finance* 11(8): 761-797.

Brock, W., Lakonishock, J. and LeBaron, B. (1992) Simple technical trading rules and the stochastic properties of stock returns. *Journal of Finance* 47(5): 1731-1764.

Brockett, P., Golden, L.L., Wen, M. and Yang, C. (2010) Pricing weather derivatives using the indifference pricing approach. *North American Actuarial Journal* 13(3): 303-315.

Brockett, P.L., Wang, M. and Yang, C. (2005) Weather Derivatives And Weather Risk Management. *Risk Management and Insurance Review* 8(1): 127-140.

Brody, D., Syroka, J. and Zervos, M. (2002) Dynamical pricing of weather derivatives. *Quantitative Finance* 2(3): 189-198.

Brogaard, J. and Garriott, C. (2018) High-Frequency Trading Competition. *Working Paper.* Available online: `https://ssrn.com/abstract=2435999`.

Brogaard, J., Hagströmer, B., Nordén, L. and Riordan, R. (2015) Trading Fast and Slow: Colocation and Liquidity. *Review of Financial Studies* 28(12): 3407-3443.

Brogaard, J., Hendershott, T. and Riordan, R. (2014) High-Frequency Trading and Price Discovery. *Review of Financial Studies* 27(8): 2267-2306.

Brooks, J. (2017) A Half Century of Macro Momentum. *Working Paper.* Available online:
`https://www.aqr.com/-/media/AQR/Documents/Insights/White-Papers/A-Half-Century-of-Macro-Momentum.pdf`.

Brooks, C. and Chong, J. (2001) The Cross-Currency Hedging Performance of Implied Versus Statistical Forecasting Models. *Journal of Futures Markets* 21(11): 1043-1069.

Brooks, C., Davies, R.J. and Kim, S.S. (2007) Cross Hedging with Single Stock Futures. *Assurances et Gestion des Risques* 74(4): 473-504.

Brooks, C., Henry, O.T. and Persand, G. (2002) The Effect of Asymmetries on Optimal Hedge Ratios. *Journal of Business* 75(2): 333-352.

Brooks, J. and Moskowitz, T.J. (2017) Yield Curve Premia. *Working Paper.* Available online: `https://ssrn.com/abstract=2956411`.

Brown, D. (1999) The Determinants of Expected Returns on Mortgage-backed Securities: An Empirical Analysis of Option-adjusted Spreads. *Journal of Fixed Income* 9(2): 8-18.

Brown, P. and Clarke, A. (1993) The Ex-Dividend Day Behaviour of Australian Share Prices Before and After Dividend Imputation. *Australian Journal of Management* 18(1): 1-40.

Brown, D.C., Davies, S. and Ringgenberg, M. (2018) ETF Arbitrage and Return Predictability. *Working Paper.* Available online: `https://ssrn.com/abstract=2872414`.

Brown, S.J., Goetzmann, W., Ibbotson, R.G. and Ross, S.A. (1992) Survivorship Bias in Performance Studies. *Review of Financial Studies* 5(4): 553-580.

Brown, S.J., Grundy, B.D., Lewis, C.M. and Verwijmeren, P. (2012) Convertibles and hedge funds as distributors of equity exposure. *Review of Financial Studies* 25(10): 3077-3112.

Brown, K.C. and Raymond, M.V. (1986) Risk arbitrage and the prediction of successful corporate takeovers. *Financial Management* 15(3): 54-63.

Browne, S. (2000) Risk-constrained dynamic active portfolio management. *Management Science* 46(9): 1188-1199.

Brück, E. and Fan, Y. (2017) Smart Beta In Global Government Bonds And Its Risk Exposure. *Working Paper.* Available online: https://www.cfasociety.org/France/Documents/QuantAwards2017_Etienne%20BRUECK%20and%20Yuanting%20FAN_EDHEC.pdf.

Bruder, B., Dao, T.-L., Richard, R.-J. and Roncalli, T. (2013) Trend Filtering Methods for Momentum Strategies. *Working Paper.* Available online: https://ssrn.com/abstract=2289097.

Brunnermeier, M.K., Nagel, S. and Pedersen, L.H. (2008) Carry Trades and Currency Crashes. *NBER Macroeconomics Annual* 23(1): 313-347.

Bu, Q. and Lacey, N. (2007) Exposing Survivorship Bias in Mutual Fund Data. *Journal of Business and Economics Studies* 13(1): 22-37.

Budish, E., Cramton, P. and Shim, J. (2015) The High-Frequency Trading Arms Race: Frequent Batch Auctions as a Market Design Response. *Quarterly Journal of Economics* 130(4): 1547-1621.

Buetow, G.W. and Henderson, B.J. (2012) An empirical analysis of exchange-traded funds. *Journal of Portfolio Management* 38(4): 112-127.

Buetow, G.W. and Henderson, B.J. (2016) The VIX Futures Basis: Determinants and Implications. *Journal of Portfolio Management* 42(2): 119-130.

Bühler, W. and Kempf, A. (1995) DAX index futures: Mispricing and arbitrage in German markets. *Journal of Futures Markets* 15(7): 833-859.

Bundgaard, J. (2013) Coordination Rules as a Weapon in the War against Cross-Border Tax Arbitrage – The Case of Hybrid Entities and Hybrid Financial Instruments. *Bulletin for International Taxation*, April/May 2013, pp. 200-204.

Buraschi, A. and Jiltsov, A. (2005) Inflation Risk Premia and the Expectations Hypothesis. *Journal of Financial Economics* 75(2): 429-490.

Burnside, C., Eichenbaum, M., Kleshchelski, I. and Rebelo, S. (2011) Do peso problems explain the returns to the carry trade? *Review of Financial Studies* 24(3): 853-891.

Burnside, C., Eichenbaum, M. and Rebelo, S. (2007) The Returns to Currency Speculation in Emerging Markets. *American Economic Review* 97(2): 333-338.

Burnside, C., Eichenbaum, M. and Rebelo, S. (2008) Carry Trade: The Gains of Diversification. *Journal of the European Economic Association* 6(2/3): 581-588.

Burnside, C., Eichenbaum, M. and Rebelo, S. (2011) Carry trade and momentum in currency markets. *Annual Review of Financial Economics* 3: 511-535.

Burtshell, X., Gregory, J. and Laurent, J.-P. (2009) A comparative analysis of CDO pricing models under the factor copula framework. *Journal of Derivatives* 16(4): 9-37.

Busch, T., Christensen, B.J. and Nielsen, M.Ø. (2011) The Role of Implied Volatility in Forecasting Future Realized Volatility and Jumps in Foreign Exchange, Stock, and Bond Markets. *Journal of Econometrics* 160(1): 48-57.

Buser, S.A. and Hess, P.J. (1986) Empirical determinants of the relative yields on taxable and tax-exempt securities. *Journal of Financial Economics* 17(2): 335-355.

Butterworth, D. and Holmes, P. (2010) Mispricing in stock index futures contracts: evidence for the FTSE 100 and FTSE mid 250 contracts. *Applied Economics Letters* 7(12): 795-801.

Buttimer, R.J., Hyland, D.C. and Sanders, A.B. (2005) REITs, IPO Waves, and Long-Run Performance. *Real Estate Economics* 33(1): 51-87.

Caginalp, G., DeSantis, M. and Sayrak, A. (2014) The nonlinear price dynamics of US equity ETFs. *Journal of Econometrics* 183(2): 193-201.

Calamos, N.P. (2003) *Convertible Arbitrage: Insights and Techniques for Successful Hedging.* Hoboken, NJ: John Wiley & Sons, Inc.

Caldeira, J. and Moura, G.V. (2013) Selection of a portfolio of pairs based on cointegration: A statistical arbitrage strategy. *Working Paper.* Available online: `https://ssrn.com/abstract=2196391`.

Callaghan, S.R. and Barry, C.B. (2003) Tax-induced trading of equity securities: Evidence from the ADR market. *Journal of Finance* 58(4): 1583-1611.

Callejón, A.M., Casado, A.M., Fernández, M.A. and Peláez, J.I. (2013) A System of Insolvency Prediction for industrial companies using a financial alternative model with neural networks. *International Journal of Computational Intelligence Systems* 6(1): 29-37.

Campbell, J.Y. (1991) A Variance Decomposition for Stock Returns. *Economic Journal* 101(405): 157-179.

Campbell, J.Y., Chan, Y.L. and Viceira, L.M. (2003) A multivariate model of strategic asset allocation. *Journal of Financial Economics* 67(1): 41-80.

Campbell, S.D. and Diebold, F.X. (2005) Weather forecasting for weather derivatives. *Journal of the American Statistical Association* 100(469): 6-16.

Campbell, J.Y., Hilscher, J. and Sziglayi, J. (2008) In Search of Distress Risk. *Journal of Finance* 63(6): 2899-2939.

Campbell, J.Y., Shiller, R.J. and Viceira, L.M. (2009) Understanding Inflation-Indexed Bond Markets. In: Romer, D. and Wolfers, J. (eds.) *Brookings Papers on Economic Activity.* Washington, DC: Brookings Institution Press, pp. 79-120.

Campbell, J.Y., Sunderam, A. and Viceira, L.M. (2017) Inflation Bets or Deflation Hedges? The Changing Risks of Nominal Bonds. *Critical Finance Review* 6(2): 263-301.

Campbell, J.Y. and Viceira, L.M. (2004) Long-Horizon Mean-Variance Analysis: A User Guide. *Working Paper.* Available online: `http://www.people.hbs.edu/lviceira/faj_cv_userguide.pdf`.

Campbell, J.Y. and Viceira, L.M. (2005) The Term Structure of the Risk: Return Trade-Off. *Financial Analysts Journal* 61(1): 34-44.

Canina, L. and Figlewski, S. (1993) The Informational Content of Implied Volatility. *Review of Financial Studies* 6(3): 659-681.

Cao, C., Chen, Y., Liang, B. and Lo, A.W. (2013) Can hedge funds time market liquidity? *Journal of Financial Economics* 109(2): 493-516.

Cao, C., Goldie, B., Liang, B. and Petrasek, L. (2016) What Is the Nature of Hedge Fund Manager Skills? Evidence from the Risk-Arbitrage Strategy. *Journal of Financial and Quantitative Analysis* 51(3): 929-957.

Cao, M. and Wei, J. (2000) Pricing the weather. *Risk*, May 2000, pp. 67-70.

Cao, M. and Wei, J. (2004) Weather derivatives valuation and market price of weather risk. *Journal of Futures Markets* 24(11): 1065-1089.

Caplin, A. and Leahy, J. (2011) Trading Frictions and House Price Dynamics. *Journal of Money, Credit and Banking* 43(7): 283-303.

Capozza, D.R., Hendershott, P.H. and Mack, C. (2004) An Anatomy of Price Dynamics in Illiquid Markets: Analysis and Evidence from Local Housing Markets. *Real Estate Economics* 32(1): 1-32.

Carhart, M.M. (1997) Persistence in mutual fund performance. *Journal of Finance* 52(1): 57-82.

Carhart, M.M., Carpenter, J.N., Lynch, A.W. and Musto, D.K. (2002) Mutual Fund Survivorship. *Review of Financial Studies* 15(5): 1439-1463.

Carmona, R. and Crépey, S. (2010) Particle methods for the estimation of credit portfolio loss distributions. *International Journal of Theoretical and Applied Finance* 13(4): 577-602.

Carmona, R. and Durrleman, V. (2003) Pricing and Hedging Spread Options. *SIAM Review* 45(4): 627-685.

Carr, P. and Javaheri, A. (2005) The forward PDE for European options on stocks with fixed fractional jumps. *International Journal of Theoretical and Applied Finance* 8(2): 239-253.

Carr, P. and Lee, R. (2007) Realized volatility and variance: Options via swaps. *Risk* 20(5): 76-83.

Carr, P. and Lee, R. (2009) Volatility Derivatives. *Annual Review of Financial Economics* 1: 319-339.

Carr, P., Lee, R. and Wu, L. (2012) Variance swaps on time-changed Lévy processes. *Finance and Stochastics* 16(2): 335-355.

Carr, P. and Wu, L. (2009) Variance risk premiums. *Review of Financial Studies* 22(3): 1311-1341.

Carr, P. and Wu, L. (2016) Analyzing volatility risk and risk premium in option contracts: A new theory. *Journal of Financial Economics* 120(1): 1-20.

Carrasco, C.G. (2007) Studying the properties of the correlation trades. *Working Paper.* Available online: https://mpra.ub.uni-muenchen.de/22318/1/MPRA_paper_22318.pdf.

Carrion, A. (2013) Very fast money: High-frequency trading on the NASDAQ. *Journal of Financial Markets* 16(4): 680-711.

Carrion, A. and Kolay, M. (2017) Trade Signing in Fast Markets. *Working Paper.* Available online: https://ssrn.com/abstract=2489868.

Carron, A.S. and Hogan, M. (1988) The option valuation approach to mortgage pricing. *Journal of Real Estate Finance and Economics* 1(2): 131-149.

Cartea, A. and Figueroa, M. (2005) Pricing in electricity markets: a mean reverting jump diffusion model with seasonality. *Applied Mathematical Finance* 12(4): 313-335.

Cartea, A. and Pedraz, C.G. (2012) How Much Should We Pay for Interconnecting Electricity Markets? A Real Options Approach. *Energy Economics* 34(1): 14-30.

Carter, C., Rausser, G. and Schmitz, A. (1983) Efficient asset portfolios and the theory of normal backwardation. *Journal of Political Economy* 91(2): 319-331.

Casassus, J. and Collin-Dufresne, P. (2005) Stochastic convenience yield implied from commodity futures and interest rates. *Journal of Finance* 60(5): 2283-2331.

Case, K.E. and Shiller, R.J. (1987) Prices of Single Family Homes since 1970: New Indexes for Four Cities. *Federal Reserve Bank of Boston, New England Economic Review*, September-October 1987, pp. 45-56.

Case, K.E. and Shiller, R.J. (1989) The Efficiency of the Market for Single-Family Homes. *American Economic Review* 79(1): 125-137.

Case, K.E. and Shiller, R.J. (1990) Forecasting Prices and Excess Returns in the Housing Market. *Real Estate Economics* 18(3): 253-273.

Caskey, J.P. (1991) Pawnbroking in America: the Economics of a Forgotten Credit Market. *Journal of Money, Credit and Banking* 23(1): 85-99.

Cassano, M. and Sick, G. (2013) Valuation of a spark spread: an LM6000 power plant. *European Journal of Finance* 18(7-8): 689-714.

Castelino, M.G and Vora, A. (1984) Spread volatility in commodity futures: The length effect. *Journal of Futures Markets* 4(1): 39-46.

Cavaglia, S. and Vadim, M. (2002) Cross-Industry, Cross Country Allocation. *Financial Analysts Journal* 58(6): 78-97.

Cecchetti, S.G., Cumby, R.E. and Figlewski, S. (1988) Estimation of the Optimal Futures Hedge. *Review of Economics and Statistics* 70(4): 623-630.

Čerović, S. and Pepić, M. (2011) Interest rate derivatives in developing countries in Europe. *Perspectives of Innovation in Economics and Business* 9(3): 38-42.

Čerović, S., Pepić, M., Čerović, S. and Čerović, N. (2014) Duration and convexity of bonds. *Singidunum Journal of Applied Sciences* 11(1): 53-66.

Cerrato, M. and Djennad, A. (2008) Dynamic Option Adjusted Spread and the Value of Mortgage Backed Securities. *Working Paper.* Available online: `https://www.gla.ac.uk/media/media_71226_en.pdf`.

Chaboud, A.P. and Wright, J.H. (2005) Uncovered interest parity: it works, but not for long. *Journal of International Economics* 66(2): 349-362.

Chaiyapo, N. and Phewchean, N. (2017) An application of Ornstein-Uhlenbeck process to commodity pricing in Thailand. *Advances in Difference Equations* 2017: 179.

Chakravarty, S., Gulen, H. and Mayhew, S. (2004) Informed Trading in Stock and Option Markets. *Journal of Finance* 59(3): 1235-1257.

Chalmers, J.M.R. (1998) Default Risk Cannot Explain the Muni Puzzle: Evidence from Municipal Bonds that are Secured by U.S. Treasury Obligations. *Review of Financial Studies* 11(2): 281-308.

Chambers, D.R., Foy, M., Liebner, J. and Lu, Q. (2014) Index Option Returns: Still Puzzling. *Review of Financial Studies* 27(6): 1915-1928.

Chan, E.P. (2013) *Algorithmic Trading: Winning Strategies and Their Rationale.* Hoboken, NJ: John Wiley & Sons, Inc.

Chan, A.W.H. and Chen, N.-F. (2007) Convertible bond underpricing: Renegotiable covenants, seasoning, and convergence. *Management Science* 53(11): 1793-1814.

Chan, K.C. and Chen, N.-F. (1991) Structural and Return Characteristics of Small and Large Firms. *Journal of Finance* 46(4): 1467-1484.

Chan, K. and Chung, Y.P. (1993) Intraday relationships among index arbitrage, spot and futures price volatility, and spot market volume: A transactions data test. *Journal of Banking & Finance* 17(4): 663-687.

Chan, K.C., Hendershott, P.H. and Sanders, A.B. (1990) Risk and Return on Real Estate: Evidence from Equity REITs. *AREUEA Journal* 18(4): 431-452.

Chan, K.C., Jegadeesh, N. and Lakonishok, J. (1996) Momentum Strategies. *Journal of Finance* 51(5): 1681-1713.

Chan, S.H., Leung, W.K. and Wang, K. (1998) Institutional Investment in REITs: Evidence and Implications. *Journal of Real Estate Research* 16(3): 357-374.

Chan, K.F., Treepongkaruna, S., Brooks, R. and Gray, S. (2011) Asset market linkages: Evidence from financial, commodity and real estate assets. *Journal of Banking & Finance* 35(6): 1415-1426.

Chance, D. (1994) *Managed Futures and Their Role in Investment Portfolios.* Charlottesville, VA: The Research Foundation of the Institute of Chartered Financial Analysts.

Chance, D.M. and Jordan, J.V. (1996) Duration, Convexity, and Time as Components of Bond Returns. *Journal of Fixed Income* 6(2): 88-96.

Chandra, P. (2003) Sigmoidal Function Classes for Feedforward Artificial Neural Networks. *Neural Processing Letters* 18(3): 205-215.

Chang, E.C., Cheng, J.W. and Pinegar, J.M. (1999) Does Futures Trading Increase Stock Market Volatility? The Case of the Nikkei Stock Index Futures Exchange. *Journal of Banking & Finance* 23(5): 727-753.

Chang, J.S. and Fang, H. (1990) An intertemporal measure of hedging effectiveness. *Journal of Futures Markets* 10(3): 307-321.

Chang, R.P., Ko, K.-C., Nakano, S. and Rhee, S.G. (2016) Residual Momentum and Investor Underreaction in Japan. *Working Paper.* Available online: `http://sfm.finance.nsysu.edu.tw/php/Papers/CompletePaper/134-1136665035.pdf`.

Chaput, J.S. and Ederington, L.H. (2003) Option Spread and Combination Trading. *Journal of Derivatives* 10(4): 70-88.

Chaput, J.S. and Ederington, L.H. (2005) Vertical Spread Design. *Journal of Derivatives* 12(3): 28-46.

Chaput, J.S. and Ederington, L.H. (2008) Ratio Spreads. *Journal of Derivatives* 15(3): 41-57.

Charupat, N. and Miu, P. (2011) The Pricing and Performance of Leveraged Exchange-Traded Funds. *Journal of Banking & Finance* 35(4): 966-977.

Chatterjee, S., Dhillon, U.S. and Ramírez, G.G. (1996) Resolution of Financial Distress: Debt Restructurings via Chapter 11, Prepackaged Bankruptcies, and Workouts. *Financial Management* 25(1): 5-18.

Chaudhuri, A. and De, K. (2011) Fuzzy support vector machine for bankruptcy prediction. *Applied Soft Computing* 11(2): 2472-2486.

Chaumont, S., Imkeller, P. and Müller, M. (2006) Equilibrium Trading of Climate and Weather Risk and Numerical Simulation in a Markovian Framework. *Stochastic Environment Research and Risk Assessment* 20(3): 184-205.

Chava, S. and Jarrow, R.A. (2004) Bankruptcy Prediction with Industry Effects. *Review of Finance* 8(4): 537-569.

Chaves, D.B. (2012) Eureka! A Momentum Strategy that Also Works in Japan. *Working Paper.* Available online:
https://ssrn.com/abstract=1982100.

Chaves, D.B. and Viswanathan, V. (2016) Momentum and mean-reversion in commodity spot and futures markets. *Journal of Commodity Markets* 3(1): 39-53.

Che, Y.S. (2016) *A study on the risk and return of option writing strategies* (Ph.D. Thesis). *HKBU Institutional Repository. Open Access Theses and Dissertations.* 187. Hong Kong, China: Hong Kong Baptist University. Available online: https://repository.hkbu.edu.hk/etd_oa/187/.

Che, S.Y.S. and Fung, J.K.W. (2011) The performance of alternative futures buy-write strategies. *Journal of Futures Markets* 31(12): 1202-1227.

Cheah, E.T. and Fry, J. (2015) Speculative Bubbles in Bitcoin markets? An Empirical Investigation into the Fundamental Value of Bitcoin. *Economics Letters* 130: 32-36.

Chen, M.Y. (2014) A high-order fuzzy time series forecasting model for internet stock trading. *Future Generation Computer Systems* 37: 461-467.

Chen, H.J., Chen, S.J., Chen, Z. and Li, F. (2017) Empirical Investigation of an Equity Pairs Trading Strategy. *Management Science* (forthcoming). DOI: https://doi.org/10.1287/mnsc.2017.2825.

Chen, A.H.Y., Chen, K.C. and Howell, S. (1999) An analysis of dividend enhanced convertible stocks. *International Review of Economics and Finance* 8(3): 327-338.

Chen, T.F., Chung, S.L. and Tsai, W.C. (2016) Option-Implied Equity Risk and the Cross-Section of Stock Returns. *Financial Analysts Journal* 72(6): 42-55.

Chen, S.-J., Hsieh, C., Vines, T.W. and Chiou, S. (1998) Macroeconomic Variables, Firm-Specific Variables and Returns to REITs. *Journal of Real Estate Research* 16(3): 269-278.

Chen, A.H., Kang, J. and Yang, B. (2005) A Model for Convexity-Based Cross-Hedges with Treasury Futures. *Journal of Fixed Income* 15(3): 68-79.

Chen, L., Lesmond, D.A. and Wei, J. (2007) Corporate Yield Spreads and Bond Liquidity. *Journal of Finance* 62(1): 119-149.

Chen, A.S., Leung, M.T. and Daouk, H. (2003) Application of neural networks to an emerging financial market: Forecasting and trading the Taiwan Stock Index. *Computers & Operations Research* 30(6): 901-923.

Chen, R.-R., Liu, B. and Cheng, X. (2010) Pricing the Term Structure of Inflation Risk Premia: Theory and Evidence from TIPS. *Journal of Empirical Finance* 17(4): 702-721.

Chen, Z., Mao, C.X. and Wang, Y. (2010) Why firms issue callable bonds: Hedging investment uncertainty. *Journal of Corporate Finance* 16(4): 588-607.

Chen, G., Roberts, M.C. and Thraen, C.S. (2006) Managing dairy profit risk using weather derivatives. *Journal of Agricultural and Resource Economics* 31(3): 653-666.

Chen, A.H. and Selender, A.K. (1994) Determination of Swap Spreads: An Empirical Analysis. *Cox School of Business Historical Working Papers*, No. 170. Dallas, TX: Southern Methodist University. Available online: `http://scholar.smu.edu/business_workingpapers/170`.

Chen, F. and Sutcliffe, C. (2007) Better Cross Hedges With Composite Hedging? Hedging Equity Portfolios Using Financial and Commodity Futures. *European Journal of Finance* 18(6): 575-595.

Chen, H.-L., Yang, B., Wang, G., Liu, J., Xu, X., Wang, S.-J. and Liu D.-Y. (2011) A novel bankruptcy prediction model based on an adaptive fuzzy k-nearest neighbor method. *Knowledge-Based Systems* 24(8): 1348-1359.

Cheng, M. and Madhavan, A. (2010) The Dynamics of Leveraged and Inverse Exchange-Traded Funds. *Journal of Investment Management* 7(4): 43-62.

Cheng, I.-H. and Xiong, W. (2013) Why Do Hedgers Trade so Much? *Working Paper.* Available online: `https://ssrn.com/abstract=2358762`.

Chernenko, S. and Sunderam, A. (2016) Liquidity Transformation in Asset Management: Evidence from the Cash Holdings of Mutual Funds. *Working Paper.* Available online: `http://www.nber.org/papers/w22391`.

Chernov, M. and Mueller, P. (2012) The Term Structure of Inflation Expectations. *Journal of Financial Economics* 106(2): 367-394.

Cherry, J. (2004) The Limits of Arbitrage: Evidence from Exchange Traded Funds. *Working Paper.* Available online: `https://ssrn.com/abstract=628061`.

Cheung, W. (2010) The Black-Litterman model explained. *Journal of Asset Management* 11(4): 229-243.

Cheung, C.S., Kwan, C.C.Y. and Sarkar, S. (2010) Bond Portfolio Laddering: A Mean-Variance Perspective. *Journal of Applied Finance* 20(1): 103-109.

Cheung, C.W., Kwan, C.C. and Yip, P.C. (1990) The hedging effectiveness of options and futures: a mean-gini approach. *Journal of Futures Markets* 10(1): 61-73.

Cheung, A., Roca, E. and Su, J.-J. (2015) Crypto-currency Bubbles: an Application of the Phillips-Shi-Yu (2013) Methodology on Mt. Gox Bitcoin Prices. *Applied Economics* 47(23): 2348-2358.

Chiang, T.C. and Jiang, C.X. (1995) Foreign exchange returns over short and long horizons. *International Review of Economics & Finance* 4(3): 267-282.

Chiang, M.H. and Wang, C.Y. (2002) The Impact of Futures Trading on Spot Index Volatility: Evidence from Taiwan Index Futures. *Applied Economics Letters* 9(6): 381-385.

Chidambaran, N.K., Fernando, C.S. and Spindt, P.A. (2001) Credit enhancement through financial engineering: Freeport McMoRan's gold-denominated depositary shares. *Journal of Financial Economics* 60(2-3): 487-528.

Chin, J.Y.F., Prevost, A.K. and Gottesman, A.A. (2002) Contrarian investing in a small capitalization market: Evidence from New Zealand. *Financial Review* 37(3): 421-446.

Chinco, A. and Mayer, C. (2012) Distant speculators and asset bubbles in the housing market. *Working Paper.* Available online: `http://www.econ.yale.edu/~shiller/behfin/2012-04-11/Chinco_Mayer.pdf`.

Chinloy, P. (1989) The Probability of Prepayment. *Journal of Real Estate Finance and Economics* 2(4): 267-283.

Cho, M. (1996) House Price Dynamics: A Survey of Theoretical and Empirical Issues. *Journal of Housing Research* 7(2): 145-172.

Choi, M.S. (2011) Momentary exchange rate locked in a triangular mechanism of international currency. *Applied Economics* 43(16): 2079-2087.

Choi, D., Getmansky, M., Henderson, B. and Tookes, H. (2010) Convertible bond arbitrageurs as suppliers of capital. *Review of Financial Studies* 23(6): 2492-2522.

Choi, D., Getmansky, M. and Tookes, H. (2009) Convertible bond arbitrage, liquidity externalities, and stock prices. *Journal of Financial Economics* 91(2): 227-251.

Choi, H.I., Kwon, S.-H., Kim, J.Y. and Jung, D.-S. (2014) Commodity Futures Term Structure Model. *Bulletin of the Korean Mathematical Society* 51(6): 1791-1804.

Chong, E., Han, C. and Park, F.C. (2017) Deep learning networks for stock market analysis and prediction: Methodology, data representations, and case studies. *Expert Systems with Applications* 83: 187-205.

Chong, J. and Miffre, J. (2010) Conditional Correlation and Volatility in Commodity Futures and Traditional Asset Markets. *Journal of Alternative Investments* 12(3): 61-75.

Chordia, T., Goyal, A., Sadka, G., Sadka, R. and Shivakumar, L. (2009) Liquidity and the Post-Earnings-Announcement Drift. *Financial Analysts Journal* 65(4): 18-32.

Chordia, T. and Shivakumar, L. (2002) Momentum, Business Cycle, and Time-Varying Expected Returns. *Journal of Finance* 57(2): 985-1019.

Chordia, T. and Shivakumar, L. (2006) Earnings and price momentum. *Journal of Financial Economics* 80(3): 627-656.

Choroś-Tomczyk, B., Härdle, W.K. and Okhrin, O. (2016) A semiparametric factor model for CDO surfaces dynamics. *Journal of Multivariate Analysis* 146: 151-163.

Choudhry, M. (2004) The credit default swap basis: analysing the relationship between cash and synthetic credit markets. *Journal of Derivatives Use, Trading and Regulation* 10(1): 8-26.

Choudhry, M. (2006) Revisiting the Credit Default Swap Basis: Further Analysis of the Cash and Synthetic Credit Market Differential. *Journal of Structured Finance* 11(4): 21-32.

Choudhry, M. (2007) Trading the CDS Basis: Illustrating Positive and Negative Basis Arbitrage Trades. *Journal of Trading* 2(1): 79-94.

Christensen, M. (1999) Duration and Convexity for Bond Portfolios. *Finanzmarkt und Portfolio Management* 13(1): 66-72.

Christensen, P.E. and Fabozzi, F.J. (1985) Bond Immunization: An Asset Liability Optimization Strategy. In: Fabozzi, F.J. and Pollack, I.M. (eds.) *The Handbook of Fixed Income Securities.* (2nd ed.) Homewood, IL: Dow Jones-Irwin, pp. 676-703.

Christensen, J.H.E. and Gillan, J.M. (2012) Could the U.S. Treasury Benefit from Issuing More TIPS? *Federal Reserve Bank of San Francisco, Working Papers Series*, No. 2011-16. Available online: https://www.frbsf.org/economic-research/files/wp11-16bk.pdf.

Christensen, J.H.E., Lopez, J.A. and Rudebusch, G.D. (2010) Inflation Expectations and Risk Premiums in an Arbitrage-Free Model of Nominal and Real Bond Yields. *Journal of Money, Credit, and Banking* 42(6): 143-178.

Christensen, B.J. and Prabhala, N.R. (1998) The relation between implied and realized volatility. *Journal of Financial Economics* 50(2): 125-150.

Christiansen, C. and Lund, J. (2005) Revisiting the Shape of the Yield Curve: The Effect of Interest Rate Volatility. *Working Paper.* Available online: https://ssrn.com/abstract=264139.

Christie-David, R. and Chaudry, M. (2001) Coskewness and cokurtosis in futures markets. *Journal of Empirical Finance* 8(1): 55-81.

Christoffersen, S.E.K., Géczy, C.C., Musto, D.K. and Reed, A.V. (2005) Cross-border Dividend Taxation and the Preferences of Taxable and Nontaxable Investors: Evidence From Canada. *Journal of Financial Economics* 78(1): 121-144.

Christoffersen, S.E.K., Reed, A.V., Géczy, C.C. and Musto, D.K. (2003) The Limits to Dividend Arbitrage: Implications for Cross Border Investment. *Working Paper.* Available online: https://ssrn.com/abstract=413867.

Chua, C.T., Koh, W.T.H. and Ramaswamy, K. (2006) Profiting from Mean-Reverting Yield Curve Trading Strategies. *Journal of Fixed Income* 15(4): 20-33.

Chuang, H. (2015) Time Series Residual Momentum. *Working Paper.* Available online: http://www.econ.tohoku.ac.jp/econ/datascience/DDSR-DP/no38.pdf.

Chuang, H. and Ho, H.-C. (2014) Implied Price Risk and Momentum Strategy. *Review of Finance* 18(2): 591-622.

Chui, A.C.W., Titman, S. and Wei, K.C.J. (2003a) The Cross-Section of Expected REIT Returns. *Real Estate Economics* 31(3): 451-479.

Chui, A.C.W., Titman, S. and Wei, K.C.J. (2003b) Intra-industry momentum: the case of REITs. *Journal of Financial Markets* 6(3): 363-387.

Chung, S.Y. (2000) Review of Macro Trading and Investment Strategies: Macroeconomic Arbitrage in Global Markets. *Journal of Alternative Investments* 3(1): 84-85.

Ciaian, P., Rajcaniova, M. and Kancs, D. (2015) The economics of BitCoin price formation. *Applied Economics* 48(19): 1799-1815.

Cirelli, S., Vitali, S., Ortobelli Lozza, S. and Moriggia, V. (2017) A conservative discontinuous target volatility strategy. *Investment Management and Financial Innovations* 14(2-1): 176-190.

Clare, A.D., Ioannides, M. and Skinner, F.S. (2000) Hedging Corporate Bonds with Stock Index Futures: A Word of Caution. *Journal of Fixed Income* 10(2): 25-34.

Clarida, R.H., Davis, J.M. and Pedersen, N. (2009) Currency carry trade regimes: Beyond the Fama regression. *Journal of International Money and Finance* 28(8): 1375-1389.

Clarida, R. and Waldman, D. (2007) Is Bad News About Inflation Good News for the Exchange Rate? *Working Paper.* Available online: `http://www.nber.org/papers/w13010.pdf`.

Clark, G.L. (2017) Financial intermediation, infrastructure investment and regional growth. *Area Development and Policy* 2(3): 217-236.

Clark, G.L., Monk, A.H.B., Orr, R. and Scott, W. (2012) The new Era of infrastructure investing. *Pensions: An International Journal* 17(2): 103-111.

Clark, T.E. and Terry, S.J. (2010) Time Variation in the Inflation Passthrough of Energy Prices. *Journal of Finance* 42(7): 1419-1433.

Clark, T.A. and Weinstein, M.I. (1983) The behavior of the common stock of bankrupt firms. *Journal of Finance* 38(2): 489-504.

Clarke, R.G., de Silva, H. and Thorley, S. (2006) Minimum-Variance Portfolios in the U.S. Equity Market. *Journal of Portfolio Management* 33(1): 10-24.

Clarke, R.G., de Silva, H. and Thorley, S. (2010) Know Your VMS Exposure. *Journal of Portfolio Management* 36(2): 52-59.

Clarke, R.G., de Silva, H. and Thorley, S. (2013) *Fundamentals of Futures and Options.* New York, NY: The Research Foundation of CFA Institute.

Clifford, C.P., Fulkerson, J.A. and Jordan, B.D. (2014) What Drives ETF Flows? *Financial Review* 49(3): 619-642.

Clinton, K. (1988) Transactions costs and covered interest arbitrage: Theory and evidence. *Journal of Political Economy* 96(2): 358-370.

Cochrane, J.H. (1999) Portfolio Advice for a Multifactor World. *Federal Reserve Bank of Chicago, Economic Perspectives* 23(3): 59-78.

Cochrane, J.H. and Piazzesi, M. (2005) Bond Risk Premia. *American Economic Review* 95(1): 138-160.

Coffey, N., Hrung, W.B. and Sarkar, A. (2009) Capital constraints, counterparty risk, and deviations from covered interest rate parity. *Federal Reserve Bank of New York Staff Reports*, No. 393. Available online: https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr393.pdf.

Cohen, G. (2005) *The bible of options strategies: the definitive guide for practical trading strategies.* Upper Saddle River, NJ: Financial Times Prentice Hall.

Cole, C.A., Kastens, T.L., Hampel, F.A. and Gow, L.R. (1999) A calendar spread trading simulation of seasonal processing spreads. In: *Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management.* Available online: http://www.farmdoc.illinois.edu/nccc134/conf_1999/pdf/confp14-99.pdf.

Cole, C.S. and Young, P.J. (1995) Modified duration and convexity with semiannual compounding. *Journal of Economics and Finance* 19(1): 1-15.

Colianni, S., Rosales, S. and Signorotti, M. (2015) Algorithmic Trading of Cryptocurrency Based on Twitter Sentiment Analysis. *Working Paper.* Available online: http://cs229.stanford.edu/proj2015/029_report.pdf.

Collin-Dufresne, P. and Solnik, B. (2001) On the Term Structure of Default Premia in the Swap and LIBOR Markets. *Journal of Finance* 56(3): 1095-1115.

Cong, J., Tan, K.S. and Weng, C. (2013) VAR-Based Optimal Partial Hedging. *ASTIN Bulletin: The Journal of the IAA* 43(3): 271-299.

Cong, J., Tan, K.S. and Weng, C. (2014) CVaR-Based Optimal Partial Hedging. *Journal of Risk* 16(3): 49-83.

Connor, G. and Leland, H. (1995) Cash Management for Index Tracking. *Financial Analysts Journal* 51(6): 75-80.

Connor, G. and Woo, M. (2004) An Introduction to hedge funds. *Working Paper.* Available online: http://eprints.lse.ac.uk/24675/1/dp477.pdf.

Conover, C.M., Jensen, G., Johnson, R. and Mercer, M. (2008) Sector Rotation and Monetary Conditions. *Journal of Investing* 28(1): 34-46.

Conover, C.M., Jensen, G.R., Johnson, R.R. and Mercer, J.M. (2010) Is Now the Time to Add Commodities to Your Portfolio? *Journal of Investing* 19(3): 10-19.

Conrad, J., Dittmar, R.F. and Ghysels, E. (2013) Ex Ante Skewness and Expected Stock Returns. *Journal of Finance* 68(1): 85-124.

Conrad, J.S., Hameed, A. and Niden, C. (1994) Volume and autocovariances in short-horizon individual security returns. *Journal of Finance* 49(4): 1305-1329.

Conrad, J. and Kaul, G. (1998) An Anatomy of Trading Strategies. *Review of Financial Studies* 11(3): 489-519.

Cont, R. and Minca, A. (2013) Recovering Portfolio Default Intensities Implied by CDO Quotes. *Mathematical Finance* 23(1): 94-121.

Cook, T.Q. and LaRoche, R.B. (eds.) (1993) *Instruments of the money market.* (7th ed.) Richmond, Virginia: Federal Reserve Bank of Richmond.

Cook, T.Q. and Rowe, T.D. (eds.) (1986) *Instruments of the money market.* (6th ed.) Richmond, Virginia: Federal Reserve Bank of Richmond.

Cooper, T. (2010) Alpha Generation and Risk Smoothing Using Managed Volatility. *Working Paper.* Available online: https://ssrn.com/abstract=1664823.

Cooper, M., Downs, D.H. and Patterson, G.A. (1999) Real Estate Securities and a Filter-based, Short-term Trading Strategy. *Journal of Real Estate Research* 18(2): 313-334.

Cooper, M.J., Gutierrez, R.C., Jr. and Hameed, A. (2004) Market States and Momentum. *Journal of Finance* 59(3): 1345-1365.

Cooper, I. and Priestley, R. (2008) Time-Varying Risk Premiums and the Output Gap. *Review of Financial Studies* 22(7): 2801-2833.

Copeland, T.E. and Galai, D. (1983) Information Effects on the bid-ask spread. *Journal of Finance* 38(5): 1457-1469.

Corbally, M. and Dang, P. (2002) Underlying Markets and Indexes. In: Banks, E. (ed.) *Weather Risk Management: Market, Products and Applications.* London, UK: Palgrave Macmillan.

Corbett, M. (2006) *Find it, fix it, flip it! Make millions in real estate – one house at a time.* New York, NY: Plume.

Cornell, B. and French, K.R. (1983) The pricing of stock index futures. *Journal of Futures Markets* 3(1): 1-14.

Cornelli, F. and Li, D.D. (2002) Risk Arbitrage in Takeovers. *Review of Financial Studies* 15(3): 837-868.

Corrado, C.J. and Miller, T.W., Jr. (2005) The forecast quality of CBOE implied volatility indexes. *Journal of Futures Markets* 25(4): 339-373.

Corrado, C.J. and Su, T. (1997) Implied volatility skews and stock return skewness and kurtosis implied by stock option prices. *European Journal of Finance* 3(1): 73-85.

Correia, M.M., Richardson, S.A. and Tuna, A.I. (2012) Value Investing in Credit Markets. *Review of Accounting Studies* 17(3): 572-609.

Cosandier, P.-A. and Lang, B.R. (1981) Interest rate parity tests: Switzerland and some major western countries. *Journal of Banking & Finance* 5(2): 187-200.

Cousin, A. and Laurent, J. (2012) Dynamic Hedging of Synthetic CDO Tranches: Bridging the Gap between Theory and Practice. In: Bielecki, T.R., Brigo, D. and Patras, F. (eds.) *Credit Risk Frontiers.* Hoboken, NJ: John Wiley & Sons, Inc., Chapter 6.

Coval, J.D. and Shumway, T. (2001) Expected options returns. *Journal of Finance* 56(3): 983-1009.

Cover, T.M. (1984) An algorithm for maximizing expected log investment return. *IEEE Transactions on Information Theory* 30(2): 369-373.

Cox, D. (2015) *Handbook of Anti Money Laundering.* Chichester, UK: John Wiley & Sons, Ltd.

Crabbe, L.E. and Fabozzi, F.J. (2002) *Corporate Bond Portfolio Management.* Hoboken, NJ: John Wiley & Sons, Inc.

Creamer, G.G. and Freund, Y. (2007) A Boosting Approach for Automated Trading. *Journal of Trading* 2(3): 84-96.

Creamer, G.G. and Freund, Y. (2010) Automated Trading with Boosting and Expert Weighting. *Quantitative Finance* 10(4): 401-420.

Cremers, M. and Weinbaum, D. (2010) Deviations from Put-Call Parity and Stock Return Predictability. *Journal of Financial and Quantitative Analysis* 45(2): 335-367.

Creti, A., Joëts, M. and Mignon, V. (2013) On the links between stock and commodity markets' volatility. *Energy Economics* 37: 16-28.

Cross, R. and Kozyakin, V. (2015) Fact and fictions in FX arbitrage processes. *Journal of Physics: Conference Series* 585: 012015.

Cultrera, L. and Brédart, X. (2015) Bankruptcy prediction: the case of Belgian SMEs. *Review of Accounting and Finance* 15(1): 101-119.

Czaja, M.-G., Kaufmann, P. and Scholz, H. (2013) Enhancing the profitability of earnings momentum strategies: The role of price momentum, information diffusion and earnings uncertainty. *Journal of Investment Strategies* 2(4): 3-57.

Dahlgran, R.A. (2000) Cross-hedging the cottonseed crush: A case study. *Agribusiness* 16(2): 141-158.

Daigler, R.T. (2007) Spread volume for currency futures. *Journal of Economics and Finance* 31(1): 12-19.

Daigler, R.T. and Copper, M. (1998) A Futures Duration-Convexity Hedging Method. *Financial Review* 33(4): 61-80.

Dale, A. and Currie, E. (2015) An alternative funding model for agribusiness research in Canada. *Agricultural Sciences* 6(9): 961-969.

Damghani, B.M. and Kos, A. (2013) De-arbitraging With a Weak Smile: Application to Skew Risk. *Wilmott Magazine* 2013(64): 40-49.

Damiani, D. (2012) The Case for Cash. *CFA Institute Magazine* 23(4): 8-9.

D'Amico, S., Kim, D. and Wei, M. (2018) Tips from TIPS: The Informational Content of Treasury Inflation-Protected Security Prices. *Journal of Financial and Quantitative Analysis* 53(1): 395-436.

Daniel, K. (2001) The Power and Size of Mean Reversion Tests. *Journal of Empirical Finance* 8(5): 493-535.

Daniel, K. and Moskowitz, T.J. (2016) Momentum crashes. *Journal of Financial Economics* 122(2): 221-247.

D'Antonio, L. (2008) Equity Collars as Alternative to Asset Allocation. *Journal of Financial Service Professionals* 62(1): 67-76.

Dao, T.-L. (2014) Momentum strategies with the L1 filter. *Journal of Investment Strategies* 3(4): 57-82.

Das, S. (2005) *Credit Derivatives: Trading & Management of Credit & Default Risk.* (3rd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

da S. Gomes, G.S., Ludermir, T.B. and Lima, L.M.M.R. (2011) Comparison of new activation functions in neural network for forecasting financial time series. *Neural Computing and Applications* 20(3): 417-439.

Dash, R. and Dash, P.K. (2016) A hybrid stock trading framework integrating technical analysis with machine learning techniques. *Journal of Finance and Data Science* 2(1): 42-57.

Da Silva, A.S., Lee, W. and Pornrojnangkool, B. (2009) The Black-Litterman model for active portfolio management. *Journal of Portfolio Management* 35(2): 61-70.

Daumas, L.D. (2017) Hedging stocks through commodity indexes: a DCC-GARCH approach. *Working Paper.* Available online: `https://impa.br/wp-content/uploads/2017/11/RiO2017-PP_FAiube.pdf`.

Davidson, A.S., Herskovitz, M.D. and Van Drunen, L.D. (1988) The refinancing threshold pricing model: An economic approach to valuing MBS. *Journal of Real Estate Finance and Economics* 1(2): 117-130.

Davis, J.L. (1996) The cross-section of stock returns and survivorship bias: Evidence from delisted stocks. *Quarterly Review of Economics and Finance* 36(3): 365-375.

Davis, M. (2001) Pricing Weather Derivatives by Marginal Value. *Quantitative Finance* 1(3): 305-308.

Davis, M.H.A. (2006) Optimal Hedging with Basis Risk. In: Kabanov, Y., Liptser, R. and Stoyanov, J. (eds.) *From Stochastic Calculus to Mathematical Finance.* Berlin, Germany: Springer.

Davis, M. and Lleo, S. (2012) Fractional Kelly strategies in continuous time: Recent developments. In: MacLean, L.C. and Ziemba, W. (eds.) *Handbook of the Fundamentals of Financial Decision Making.* Singapore: World Scientific Publishing.

Davis, M. and Lo, V. (2001) Infectious defaults. *Quantitative Finance* 1(4): 382-387.

Deacon, M., Derry, A. and Mirfendereski, D. (2004) *Inflation-indexed Securities: Bonds, Swaps and other Derivatives.* Chichester, UK: John Wiley & Sons, Ltd.

Deardorff, A.V. (1979) One-Way Arbitrage and Its Implications for the Foreign Exchange Markets. *Journal of Political Economy* 87(2): 351-364.

de Boer, P.-T., Kroese, D.P., Mannor, S. and Rubinstein, R.Y. (2005) A Tutorial on the Cross-Entropy Method. *Annals of Operations Research* 134(1): 19-67.

DeBondt, W.F.M. and Thaler, R.H. (1985) Does stock market overreact? *Journal of Finance* 40(3): 793-807.

De Carvalho, R.L., Dugnolle, P., Lu, X. and Moulin, P. (2014) Low-Risk Anomalies in Global Fixed Income: Evidence from Major Broad Markets. *Journal of Fixed Income* 23(4): 51-70.

Dechant, T. and Finkenzeller, K. (2013) How much into infrastructure? Evidence from dynamic asset allocation. *Journal of Property Research* 30(2): 103-127.

Dechario, T., Mosser, P., Tracy, J., Vickery, J. and Wright, J. (2010) A Private Lender Cooperative Model for Residential Mortgage Finance. *Federal Reserve Bank of New York Staff Reports*, No. 466. Available online: `https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr466.pdf`.

De Jong, A., Dutordoir, M. and Verwijmeren, P. (2011) Why do convertible issuers simultaneously repurchase stock? An arbitrage-based explanation. *Journal of Financial Economics* 100(1): 113-129.

De La Peña, J.I., Garayeta, A. and Iturricastillo, I. (2017) Dynamic immunisation does not imply cash flow matching: a hard application to Spain. *Economic Research – Ekonomska Istraživanja* 30(1): 238-255.

DeLisle, J., Doran, J. and Krieger, K. (2014) Volatility as an Asset Class: Holding VIX in a Portfolio. *Working Paper.* Available online: `https://ssrn.com/abstract=2534081`.

DeMaskey, A.L. (1995) A Comparison of the Effectiveness of Currency Futures and Currency Options in the Context of Foreign Exchange Risk Management. *Managerial Finance* 21(4): 40-51.

DeMaskey, A.L. (1997) Single and Multiple Portfolio Cross-Hedging with Currency Futures. *Multinational Finance Journal* 1(1): 23-46.

DeMaskey, A.L. and Pearce, J.A. (1998) Commodity and Currency Futures Cross-Hedging of ASEAN Currency Exposures. *Journal of Transnational Management Development* 4(1): 5-24.

Demeterfi, K., Derman, E., Kamal, M. and Zou, J. (1999) A guide to volatility and variance swaps. *Journal of Derivatives* 6(4): 9-32.

DeMiguel, V., Plyakha, Y., Uppal, R. and Vilkov, G. (2013) Improving Portfolio Selection Using Option-Implied Volatility and Skewness. *Journal of Financial and Quantitative Analysis* 48(6): 1813-1845.

DeMoura, C.E., Pizzinga, A. and Zubelli, J. (2016) A pairs trading strategy based on linear state space models and the Kalman filter. *Quantitative Finance* 16(10): 1559-1573.

Dempster, M.A.H. and Jones, C.M. (2002) Can channel pattern trading be profitably automated? *European Journal of Finance* 8(3): 275-301.

Deng, Q. (2008) Volatility Dispersion Trading. *Working Paper*. Available online: `https://ssrn.com/abstract=1156620`.

Deng, S.-J., Johnson, B. and Sogomonian, A. (2001) Exotic electricity options and the valuation of electricity generation and transmission assets. *Decision Support Systems* 30(3): 383-392.

Deng, G., McCann, C. and Wang, O. (2012) Are VIX Futures ETPs Effective Hedges? *Journal of Index Investing* 3(3): 35-48.

Dennis, P. and Mayhew, S. (2002) Risk-Neutral Skewness: Evidence from Stock Options. *Journal of Financial and Quantitative Analysis* 37(3): 471-493.

Dennis, P., Mayhew, S. and Stivers, C. (2006) Stock Returns, Implied Volatility Innovations, and the Asymmetric Volatility Phenomenon. *Journal of Financial and Quantitative Analysis* 41(2): 381-406.

Denton, J.W. and Hung, M.S. (1996) A comparison of nonlinear optimization methods for supervised learning in multilayer feedforward neural networks. *European Journal of Operational Research* 93(2): 358-368.

de Oliveira, F.A., Nobre, C.N. and Zárate, L.E. (2013) Applying Artificial Neural Networks to prediction of stock price and improvement of the directional prediction index – Case study of PETR4, Petrobras, Brazil. *Expert Systems with Applications* 40(18): 7596-7606.

Depken, C.A., Hollans, H. and Swidler, S. (2009) An empirical analysis of residential property flipping. *Journal of Real Estate Finance and Economics* 39(3): 248-263.

Depken, C.A., Hollans, H. and Swidler, S. (2011) Flips, flops and foreclosures: Anatomy of a real estate bubble. *Journal of Financial Economic Policy* 3(1): 49-65.

Derman, E. and Kani, I. (1994) Riding on a Smile. *Risk* 7(2): 139-145.

de Roon, F.A., Nijman, T.E. and Veld, C. (1998) Pricing Term Structure Risk in Futures Markets. *Journal of Financial and Quantitative Analysis* 33(1): 139-157.

de Roon, F.A., Nijman, T.E. and Veld, C. (2000) Hedging pressure effects in futures markets. *Journal of Finance* 55(3): 1437-1456.

Derwall, J., Huij, J., Brounen, D. and Marquering, W. (2009) REIT Momentum and the Performance of Real Estate Mutual Funds. *Financial Analysts Journal* 65(5): 24-34.

Derwall, J., Huij, J. and De Zwart, G.B. (2009) The Short-Term Corporate Bond Anomaly. *Working Paper.* Available online: `https://ssrn.com/abstract=1101070`.

D'Este, R. (2014) The Effect of Stolen Goods Markets on Crime: Evidence from a Quasi-Natural Experiment. *Working Paper.* Available online: `https://warwick.ac.uk/fac/soc/economics/research/workingpapers/2014/twerp_1040b_deste.pdf`.

Detemple, J. and Rindisbacher, M. (2010) Dynamic Asset Allocation: Portfolio Decomposition Formula and Applications. *Review of Financial Studies* 23(1): 25-100.

Detlefsen, K. and Härdle, W.K. (2013) Variance swap dynamics. *Quantitative Finance* 13(5): 675-685.

Dewally, M., Ederington, L.H. and Fernando, C.S. (2013) Determinants of Trader Profits in Commodity Futures Markets. *Review of Financial Studies* 26(10): 2648-2683.

De Wit, I. (2010) International Diversification Strategies for Direct Real Estate. *Journal of Real Estate Finance and Economics* 41(4): 433-457.

De Wit, J. (2006) Exploring the CDS-Bond Basis. *Working Paper.* Available online: `https://ssrn.com/abstract=1687659`.

de Wit, E.R. and van der Klaauw, B. (2013) Asymmetric Information and List-Price Reductions in the Housing Market. *Regional Science and Urban Economics* 43(3): 507-520.

De Zwart, G., Markwat, T., Swinkels, L. and van Dijk, D. (2009) The economic value of fundamental and technical information in emerging currency markets. *Journal of International Money and Finance* 28(4): 581-604.

Dichev, I. (1998) Is the risk of bankruptcy a systematic risk? *Journal of Finance* 53(3): 1131-1147.

Diebold, F.X. and Li, C. (2002) Forecasting the term structure of government bond yields. *Journal of Econometrics* 130(2): 337-364.

Diebold, F.X., Rudebusch, G.D. and Aruoba, S.B. (2006) The macroeconomy and the yield curve: a dynamic latent factor approach. *Journal of Econometrics* 131(1-2): 309-338.

Ding, J.J. and Sherris, M. (2011) Comparison of market models for measuring and hedging synthetic CDO tranche spread risks. *European Actuarial Journal* 1(S2): 261-281.

Disatnik, D., Duchin, R. and Schmidt, B. (2014) Cash Flow Hedging and Liquidity Choices. *Review of Finance* 18(2): 715-748.

Dischel, B. (1998a) At last: A model for weather risk. *Energy and Power Risk Management* 11(3): 20-21.

Dischel, B. (1998b) Black-Scholes won't do. *Energy and Power Risk Management* 11(10): 8-9.

Dischel, B. (1999) Shaping history for weather risk management. *Energy and Power Risk Management* 12(8): 13-15.

Do, B. and Faff, R. (2010) Does simple pairs trading still work? *Financial Analysts Journal* 66(4): 83-95.

Do, B. and Faff, R. (2012) Are pairs trading profits robust to trading costs? *Journal of Financial Research* 35(2): 261-287.

Doan, M.P., Alexeev, V. and Brooks, R. (2014) Concurrent momentum and contrarian strategies in the Australian stock market. *Australian Journal of Management* 41(1): 77-106.

Dobson, M.W.R. (1984) Global Investment Portfolios: The United Kingdom and Scandinavia. *ICFA Continuing Education Series* 1984(4): 56-60.

Doeswijk, R., Lam, T. and Swinkels, L. (2014) The Global Multi-Asset Market Portfolio, 1959-2012. *Financial Analysts Journal* 70(2): 26-41.

Doeswijk, R. and van Vliet, P. (2011) Global tactical sector allocation: a quantitative approach. *Journal of Portfolio Management* 28(1): 29-47.

Dolan, C.P. (1999) Forecasting the Yield Curve Shape. *Journal of Fixed Income* 9(1): 92-99.

Dolvin, S.D. (2009) ETFs: Arbitrage opportunities and market forecasting. *Journal of Index Investing* 1(1): 107-116.

Dolvin, S. and Kirby, J. (2011) Momentum Trading in Sector ETFs. *Journal of Index Investing* 2(3): 50-57.

Donchian, R.D. (1960) High finance in copper. *Financial Analysts Journal* 16(6): 133-142.

Dong, J.-C., Liu, J.-X., Wang, C.-H., Yuan, H. and Wang, W.-J. (2009) Pricing Mortgage-Backed Security: An Empirical Analysis. *Systems Engineering – Theory & Practice* 29(12): 46-52.

Dong, Z. and Zhou, D.-X. (2008) Learning gradients by a gradient descent algorithm. *Journal of Mathematical Analysis and Applications* 341(2): 1018-1027.

Donier, J. and Bouchaud, J.-P. (2015) Why Do Markets Crash? Bitcoin Data Offers Unprecedented Insights. *PLoS ONE* 10(10): e0139356.

Donninger, C. (2014) VIX Futures Basis Trading: The Calvados-Strategy 2.0. *Working Paper.* Available online: `https://ssrn.com/abstract=2379985`.

Donninger, C. (2015) Trading the Patience of Mrs. Yellen. A Short Vix-Futures Strategy for FOMC Announcement Days. *Working Paper.* Available online: `https://ssrn.com/abstract=2544445`.

Doran, J.S. and Krieger, K. (2010) Implications for Asset Returns in the Implied Volatility Skew. *Financial Analysts Journal* 66(1): 65-76.

Doran, J.S., Peterson, D.R. and Tarrant, B.C. (2007) Is there information in the volatility skew? *Journal of Futures Markets* 27(10): 921-959.

Dorfleitner, G. and Wimmer, M. (2010) The pricing of temperature futures at the Chicago Mercantile Exchange. *Journal of Banking & Finance* 34(6): 1360-1370.

Dornier, F. and Queruel, M. (2000) Caution to the wind. *Energy and Power Risk Management* 13(8): 30-32.

Doskov, N. and Swinkels, L. (2015) Empirical evidence on the currency carry trade, 1900-2012. *Journal of International Money and Finance* 51: 370-389.

Douglas, R. (ed.) (2007) *Credit Derivative Strategies: New Thinking on Managing Risk and Return.* New York, NY: Bloomberg Press.

Dowd, K. and Hutchinson, M. (2015) Bitcoin Will Bite the Dust. *Cato Journal* 35(2): 357-382.

Downing, C., Jaffee, D. and Wallace, N. (2009) Is the Market for Mortgage-Backed Securities a Market for Lemons? *Review of Financial Studies* 22(7): 2457-2494.

Doyle, J.T., Lundholm, R.J. and Soliman, M.T. (2006) The extreme future stock returns following I/B/E/S earnings surprises. *Journal of Accounting Research* 44(5): 849-887.

Draper, P., Faff, R.W. and Hillier, D. (2006) Do Precious Metals Shine? An Investment Perspective. *Financial Analysts Journal* 62(2): 98-106.

Dreyfus, S.E. (1990) Artificial neural networks, back propagation, and the Kelley-Bryson gradient procedure. *Journal of Guidance, Control, and Dynamics* 13(5): 926-928.

Driessen, J., Maenhout, P.J. and Vilkov, G. (2009) The Price of Correlation Risk: Evidence from Equity Options. *Journal of Finance* 64(3): 1377-1406.

Driessen, J., Nijman, T. and Simon, Z. (2017) The Missing Piece of the Puzzle: Liquidity Premiums in Inflation-Indexed Markets. *Working Paper.* Available online: `https://ssrn.com/abstract=3042506`.

Drobetz, W. (2001) How to Avoid the Pitfalls in Portfolio Optimization? Putting the Black-Litterman Approach at Work. *Financial Markets and Portfolio Management* 15(1): 59-75.

Drobny, S. (2006) *Inside the House of Money: Top Hedge Fund Traders on Profiting in the Global Markets.* Hoboken, NJ: John Wiley & Sons, Inc.

Droms, W.G. and Walker, D.A. (2001) Performance persistence of international mutual funds. *Global Finance Journal* 12(2): 237-248.

Du, W., Tepper, A. and Verdelhan, A. (2018) Deviations from Covered Interest Rate Parity. *Journal of Finance* (forthcoming). DOI: `https://doi.org/10.1111/jofi.12620`. Available online: `https://ssrn.com/abstract=2768207`.

Duarte, J., Longstaff, F.A. and Yu, F. (2006) Risk and Return in Fixed-Income Arbitrage: Nickels in Front of a Steamroller? *Review of Financial Studies* 20(3): 769-811.

Dubil, R. (2011) Hedge Funds: Alpha, Beta and Replication Strategies. *Journal of Financial Planning* 24(10): 68-77.

Duca, E., Dutordoir, M., Veld, C. and Verwijmeren, P. (2012) Why are convertible bond announcements associated with increasingly negative issuer stock returns? An arbitrage based explanation. *Journal of Banking & Finance* 36(11): 2884-2899.

Duchin, R. (2010) Cash Holdings and Corporate Diversification. *Journal of Finance* 65(3): 955-992.

Dudley, W., Roush, J.E. and Steinberg, M. (2009) The Case for Tips: An Examination of the Costs and Benefits. *Federal Reserve Bank of New York, Economic Policy Review* 15(1): 1-17.

Duffie, D. (1996) Special repo rates. *Journal of Finance* 51(2): 493-526.

Duffie, D. (2004) Time to adapt copula methods for modelling credit risk correlation. *Risk*, April 2004, p. 77.

Duffie, D. (2017) The covered interest parity conundrum. *Risk*, May 2017. Available online: https://www.risk.net/4353726.

Duffie, D. and Gârleanu, N. (2001) Risk and Valuation of Collateralized Debt Obligations. *Financial Analysts Journal* 57(1): 41-59.

Duffie, D. and Huang, M. (1996) Swap Rates and Credit Quality. *Journal of Finance* 51(2): 921-949.

Duffie, D., Saita, L. and Wang, K. (2007) Multi-period corporate default prediction with stochastic covariates. *Journal of Financial Economics* 83(3): 635-665.

Duffie, D. and Singleton, K.J. (1997a) Modeling term structures of defaultable bonds. *Review of Financial Studies* 12(4): 687-720.

Duffie, D. and Singleton, K.J. (1997b) An Econometric Model of the Term Structure of Interest Rate Swap Yields. *Journal of Finance* 52(4): 1287-1321.

DuJardin, P. (2015) Bankruptcy prediction using terminal failure processes. *European Journal of Operational Research* 242(1): 286-303.

Dukes, W.P., Frolich, C.J. and Ma, C.K. (1992) Risk arbitrage in tender offers. *Journal of Portfolio Management* 18(4): 47-55.

Dumas, B., Fleming, J. and Whaley, R. (1998) Implied Volatility Functions: Empirical Tests. *Journal of Finance* 53(6): 2059-2106.

Dunis, C., Laws, J. and Evans, B. (2006) Trading futures spreads. *Applied Financial Economics* 16(12): 903-914.

Dunis, C., Laws, J. and Evans, B. (2010) Trading and filtering futures spread portfolios. *Journal of Derivatives & Hedge Funds* 15(4): 274-287.

Dunis, C., Laws, J. and Rudy, J. (2013) Mean Reversion Based on Autocorrelation: A Comparison Using the S&P 100 Constituent Stocks and the 100 Most Liquid ETFs. *ETF Risk*, October 2013, pp. 36-41.

Dunn, K.B. and McConnell, J.J. (1981a) A Comparison of Alternative Models for Pricing GNMA Mortgage-Backed Securities. *Journal of Finance* 36(2): 471-484.

Dunn, K.B. and McConnell, J.J. (1981b) Valuation of GNMA Mortgage-Backed Securities. *Journal of Finance* 36(3): 599-616.

Dupire, B. (1994) Pricing with a smile. *Risk* 7(1): 18-20.

Dusak, K. (1973) Futures Trading and Investor Returns: An Investigation of Commodity Market Risk Premiums. *Journal of Political Economy* 81(6): 1387-1406.

Dutordoir, M., Lewis, C.M., Seward, J. and Veld, C. (2014) What we do and do not know about convertible bond financing. *Journal of Corporate Finance* 24: 3-20.

Dutt, H.R., Fenton, J., Smith, J.D. and Wang, G.H.K. (1997) Crop year influences and variability of the agricultural futures spreads. *Journal of Futures Markets* 17(3): 341-367.

Dwyer, G.P., Jr., Locke, P. and Yu, W. (1996) Index Arbitrage and Nonlinear dynamics Between the S&P 500 Futures and Cash. *Review of Financial Studies* 9(1): 301-332.

Dyhrberg, A.H. (2015) Bitcoin, gold and the dollar – a GARCH volatility analysis. *Finance Research Letters* 16: 85-92.

Dyhrberg, A.H. (2016) Hedging capabilities of bitcoin. Is it the virtual gold? *Finance Research Letters* 16: 139-144.

Dyl, E.A. and Joehnk, M.D. (1981) Riding the Yield Curve: Does it Work? *Journal of Portfolio Management* 7(3): 13-17.

Dyl, E.A. and Martin, S.A. (1986) Another Look at Barbells Versus Ladders. *Journal of Portfolio Management* 12(3): 54-59.

Dynkin, L., Hyman, J., Konstantinovsky, V. and Roth, N. (2001) Building an MBS Index: Conventions and Calculations. In: Fabozzi, F.J. (ed.) *The Handbook of Mortgage-Backed Securities.* (5th ed.) New York, NY: McGraw-Hill, Inc.

Dzikevičius, A. and Šanranda, S. (2010) EMA versus SMA: Usage to forecast Stock Markets: The Case of S&P 500 and OMX Baltic Benchmark. *Verslas: teorija ir praktika – Business: theory and practice* 11(3): 248-255.

Easley, D., López de Prado, M.M. and O'Hara, M. (2011) The microstructure of the 'flash crash': flow toxicity, liquidity crashes and the probability of informed trading. *Journal of Portfolio Management* 37(2): 118-128.

Easley, D., López de Prado, M.M. and O'Hara, M. (2012) The volume clock: Insights into the high frequency paradigm. *Journal of Portfolio Management* 39(1): 19-29.

Eastman, A.M. and Lucey, B.M. (2008) Skewness and asymmetry in futures returns and volumes. *Applied Financial Economics* 18(10): 777-800.

Eberhart, A., Altman, E. and Aggarwal, R. (1999) The Equity Performance of Firms Emerging from Bankruptcy. *Journal of Finance* 54(5): 1855-1868.

Eberhart, A.C. and Sweeney, R.J. (1992) Does the Bond Market Predict Bankruptcy Settlements? *Journal of Finance* 47(3): 943-980.

Ebrahim, S. and Rahman, S. (2005) On the pareto-optimality of futures contracts over Islamic forward contracts: Implications for the emerging Muslim economies. *Journal of Economic Behavior & Organization* 56(2): 273-295.

Ederington, L.H. (1979) The hedging performance of the new futures markets. *Journal of Finance* 34(1): 157-170.

Edwards, D.W. (2009) *Energy Trading & Investing: Trading, Risk Management and Structuring Deals in the Energy Market.* New York, NY: McGraw-Hill, Inc.

Edwards, F.R. (1988) Futures Trading and Cash Market Volatility: Stock Index and Interest Rate Futures. *Journal of Futures Markets* 8(4): 421-439.

Edwards, R. and Magee, J. (1992) *Technical Analysis of Stock Trends.* New York, NY: New York Institute of Finance.

Edwards, F.R. and Park, J.M. (1996) Do Managed Futures Make Good Investments? *Journal of Futures Markets* 16(5): 475-517.

Edwards, S. and Susmel, R. (2003) Interest-Rate Volatility in Emerging Markets. *Review of Economics and Statistics* 85(2): 328-348.

Egginton, J.F., Van Ness, B.F. and Van Ness, R.A. (2016) Quote Stuffing. *Financial Management* 45(3): 583-608.

Ehlgen, J. (1998) Distortionary effects of the optimal Hodrick-Prescott filter. *Economics Letters* 61(3): 345-349.

Eichenbaum, M. and Evans, C.L. (1995) Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates. *Quarterly Journal of Economics* 110(4): 975-1009.

Eichholtz, P.M.A., Hoesli, M., MacGregor, B.D. and Nanthakumaran, N. (1995) Real estate portfolio diversification by property type and region. *Journal of Property Finance* 6(3): 39-59.

Eisdorfer, A. and Misirli, E. (2015) Distressed Stocks in Distressed Times. *Working Paper.* Available online: https://ssrn.com/abstract=2697771.

Eisl, A., Gasser, S. and Weinmayer, K. (2015) Caveat Emptor: Does Bitcoin Improve Portfolio Diversification? *Working Paper.* Available online: https://ssrn.com/abstract=2408997.

Elder, A. (2014) *The New Trading for a Living.* Hoboken, NJ: John Wiley & Sons, Inc.

Eldred, G.W. (2004) *The Beginner's Guide to Real Estate Investing.* Hoboken, NJ: John Wiley & Sons, Inc.

Elias, R.S., Wahab, M.I.M. and Fang, L. (2016) The spark spread and clean spark spread option based valuation of a power plant with multiple turbines. *Energy Economics* 59: 314-327.

El Kalak, I. and Hudson, R. (2016) The effect of size on the failure probabilities of SMEs: An empirical study on the US market using discrete hazard model. *International Review of Financial Analysis* 43: 135-145.

Elliott, R., Siu, T. and Chan, L. (2007) Pricing volatility swaps under Heston's stochastic volatility model with regime switching. *Applied Mathematical Finance* 14(1): 41-62.

Elliott, R.J., van der Hoek, J. and Malcolm, W.P. (2005) Pairs trading. *Quantitative Finance* 5(3): 271-276.

Elton, E.J., Gruber, M.J. and Blake, C.R. (1996a) The Persistence of Risk-Adjusted Mutual Fund Performance. *Journal of Business* 69(2): 133-157.

Elton, E.J., Gruber, M.J. and Blake, C.R. (1996b) Survivor Bias and Mutual Fund Performance. *Review of Financial Studies* 9(4): 1097-1120.

Elton, E.J., Gruber, M.J. and Rentzler, J.C. (1987) Professionally Managed, Publicly Traded Commodity Funds. *Journal of Business* 60(2): 175-199.

Emery, G.W. and Liu, Q. (2002) An analysis of the relationship between electricity and natural gas futures prices. *Journal of Futures Markets* 22(2): 95-122.

Engel, C. (1996) The Forward Discount Anomaly and the Risk Premium: A Survey of Recent Evidence. *Journal of Empirical Finance* 3(2): 123-192.

Engle, R.F. and Granger, C.W.J. (1987) Co-integration and error correction: Representation, estimation and testing. *Econometrica* 55(2): 251-276.

Engle, R. and Rosenberg, J. (2000) Testing the volatility term structure using option hedging criteria. *Journal of Derivatives* 8(1): 10-28.

Engle, R.F. and Watson, M.W. (1987) The Kalman Filter: applications to forecasting and rational-expectation models. In: Bewley, T.F. (ed.) *Fifth World Conference: Advances in Econometrics*, Vol. 1. Cambridge, UK: Cambridge University Press.

Eraker, B. (2009) The Volatility Premium. *Working Paper.* Available online: `http://www.nccr-finrisk.uzh.ch/media/pdf/Eraker_23-10.pdf`.

Eraker, B. and Wu, Y. (2014) Explaining the Negative Returns to VIX Futures and ETNs: An Equilibrium Approach. *Working Paper.* Available online: `https://ssrn.com/abstract=2340070`.

Erb, C. and Harvey, C. (2006) The Strategic and Tactical Value of Commodity Futures. *Financial Analysts Journal* 62(2): 69-97.

Erickson, M., Goolsbee, A. and Maydew, E. (2003) How Prevalent is Tax Arbitrage? Evidence from the Market for Municipal Bonds. *National Tax Journal* 56(1): 259-270.

Ertugrul, M. and Giambona, E. (2011) Property Segment and REIT Capital Structure. *Journal of Real Estate Finance and Economics* 43(4): 505-526.

Espinoza, R.D. and Luccioni, L. (2002) Proper Risk Management: The Key To Successful Brownfield Development. *WIT Transactions on Ecology and the Environment* 55: 297-306.

Eun, C.S. and Sabherwal, S. (2003) Cross-border listings and price discovery: Evidence from U.S. listed Canadian stocks. *Journal of Finance* 58(2): 549-575.

Evans, M.D.D. (1998) Real Rates, Expected Inflation, and Inflation Risk Premia. *Journal of Finance* 53(1): 187-218.

Evans, C.L. and Marshall, D.A. (2007) Economic determinants of the nominal treasury yield curve. *Journal of Monetary Economics* 54(7): 1986-2003.

Faber, M. (2007) A Quantitative Approach to Tactical Asset Allocation. *Journal of Wealth Management* 9(4): 69-79.

Faber, M. (2015) Learning to Play Offense and Defense: Combining Value and Momentum from the Bottom Up, and the Top Down. *Working Paper.* Available online: https://ssrn.com/abstract=2669202.

Faber, M. (2016) The Trinity Portfolio: A Long-Term Investing Framework Engineered for Simplicity, Safety, and Outperformance. *Working Paper.* Available online: https://ssrn.com/abstract=2801856.

Fabozzi, F.J. (ed.) (2002) *The Handbook of Financial Instruments.* Hoboken, NJ: John Wiley & Sons, Inc.

Fabozzi, F.J. (2006a) *Fixed Income Mathematics: Analytical & Statistical Techniques.* New York, NY: McGraw-Hill, Inc.

Fabozzi, F.J. (ed.) (2006b) *The Handbook of Mortgage-Backed Securities.* New York, NY: McGraw-Hill, Inc.

Fabozzi, F.J. (2012a) *Bond markets, analysis, and strategies.* Upper Saddle River, NJ: Prentice Hall.

Fabozzi, F.J. (2012b) *Institutional Investment Management: Equity and Bond Portfolio Strategies and Applications.* Hoboken, NJ: John Wiley & Sons, Inc.

Fabozzi, F.J., Focardi, S.M. and Jonas, C. (2010) *Investment Management after the Global Financial Crisis.* Charlottesville, VA: The Research Foundation of CFA Institute.

Fabozzi, F.J. and Mann, S.V. (2010) *Introduction to Fixed Income Analytics: Relative Value Analysis, Risk Measures, and Valuation.* Hoboken, NJ: John Wiley & Sons, Inc.

Fabozzi, F.J., Martellini, L. and Priaulet, P. (2006) *Advanced Bond Portfolio Management. Best Practices in Modeling and Strategies.* Hoboken, NJ: John Wiley & Sons, Inc.

Falkenstein, E. and Hanweck, J. (1996) Minimizing Basis Risk from Non-Parallel Shifts in the Yield Curve. *Journal of Fixed Income* 6(1): 60-68.

Fama, E.F. (1984) Forward and spot exchange rates. *Journal of Monetary Economics* 14(3): 319-338.

Fama, E.F. (1996) Multifactor Portfolio Efficiency and Multifactor Asset Pricing. *Journal of Financial and Quantitative Analysis* 31(4): 441-465.

Fama, E.F. and French, K.R. (1987) Commodity futures prices: some evidence on forecast power, premiums, and the theory of storage. *Journal of Business* 60(1): 55-73.

Fama, E.F. and French, K.R. (1988) Business Cycles and the Behavior of Metals Prices. *Journal of Finance* 43(5): 1075-1093.

Fama, E.F. and French, K.R. (1992) The Cross-Section of Expected Stock Returns. *Journal of Finance* 47(2): 427-465.

Fama, E.F. and French, K.R. (1993) Common Risk Factors in the Returns on Stocks and Bonds. *Journal of Financial Economics* 33(1): 3-56.

Fama, E.F. and French, K.R. (1996) Multifactor Explanations of Asset Pricing Anomalies. *Journal of Finance* 51(1): 55-84.

Fama, E.F. and French, K.R. (1998) Value versus Growth: The International Evidence. *Journal of Finance* 53(6): 1975-1999.

Fama, E.F. and French, K.R. (2008) Dissecting Anomalies. *Journal of Finance* 63(4): 1653-1678.

Fama, E.F. and French, K.R. (2012) Size, Value and Momentum in International Stock Returns. *Journal of Financial Economics* 105(3): 457-472.

Fama, E.F. and Schwert, G.W. (1977) Asset returns and inflation. *Journal of Financial Economics* 5(2): 115-146.

Fass, S.M. and Francis, J. (2004) Where have all the hot goods gone? The role of pawnshops. *Journal of Research in Crime and Delinquency* 41(2): 156-179.

Fassas, A.P. (2011) Mispricing in stock index futures markets – the case of Greece. *Investment Management and Financial Innovations* 8(2): 101-107.

Fedorova, E., Gilenko, E. and Dovzhenko, S. (2013) Bankruptcy prediction for Russian companies: Application of combined classifiers. *Expert Systems with Applications* 40(18): 7285-7293.

Feldhütter, P. and Lando, D. (2008) Decomposing swap spreads. *Journal of Financial Economics* 88(2): 375-405.

Feldman, B.E. (2003) Investment Policy for Securitized and Direct Real Estate. *Journal of Portfolio Management* 29(5): 112-121.

Feldman, B. and Roy, D. (2004) Passive Options-based Investment Strategies: The Case of the CBOE S&P 500 BuyWrite Index. *ETF and Indexing* 38(1): 72-89.

Feldman, B. and Till, H. (2006) Backwardation and Commodity Futures Performance: Evidence from Evolving Agricultural Markets. *Journal of Alternative Investments* 9(3): 24-39.

Félix, J.A. and Rodríguez, F.F. (2008) Improving moving average trading rules with boosting and statistical learning methods. *Journal of Forecasting* 27(5): 433-449.

Fengler, M.R., Herwartz, H. and Werner, C. (2012) A Dynamic Copula Approach to Recovering the Index Implied Volatility Skew. *Journal of Financial Econometrics* 10(3): 457-493.

Fenn, D.J., Howison, S.D., Mcdonald, M., Williams, S. and Johnson, N.F. (2009) The mirage of triangular arbitrage in the spot foreign exchange market. *International Journal of Theoretical and Applied Finance* 12(8): 1105-1123.

Fernandez-Perez, A., Frijns, B., Fuertes, A.M. and Miffre, J. (2018) The skewness of commodity futures returns. *Journal of Banking & Finance* 86: 143-158.

Fernandez-Perez, A., Fuertes, A.M. and Miffre, J. (2016) Is idiosyncratic volatility priced in commodity futures markets? *International Review of Financial Analysis* 46: 219-226.

Ferreira, S., Grammatikos, T. and Michala, D. (2016) Forecasting distress in Europe SME portfolios. *Journal of Banking & Finance* 64: 112-135.

Ferson, W. and Mo, H. (2016) Performance measurement with selectivity, market and volatility timing. *Journal of Financial Economics* 121(1): 93-110.

Fifield, S.G.M., Power, D.M. and Knipe, D.G.S. (2008) The performance of moving average rules in emerging stock markets. *Applied Financial Economics* 18(19): 1515-1532.

Figlewski, S., Chidambaran, N.K. and Kaplan, S. (1993) Evaluating the Performance of the Protective Put Strategy. *Financial Analysts Journal* 49(4): 46-56, 69.

Filipović, D., Gourier, E. and Mancini, L. (2016) Quadratic variance swap models. *Journal of Financial Economics* 119(1): 44-68.

Finger, C.C. (1999) Conditional approaches for credit metrics portfolio distributions. *Credit Metrics Monitor* 2(1): 14-33.

Finkenzeller, K., Dechant, T. and Schäfers, W. (2010) Infrastructure: a new dimension of real estate? An asset allocation analysis. *Journal of Property Investment & Finance* 28(4): 263-274.

Finnerty, J.D. and Tu, M. (2017) Valuing Convertible Bonds: A New Approach. *Business Valuation Review* 36(3): 85-102.

Fiorenzani, S. (2006) *Quantitative Methods for Electricity Trading and Risk Management: Advanced Mathematical and Statistical Methods for Energy Finance.* London, UK: Palgrave Macmillan.

Firstenberg, P.M., Ross, S.A. and Zisler, R.C. (1988) Real estate: The whole story. *Journal of Portfolio Management* 14(3): 22-34.

Fishe, R.P.H., Janzen, J.P. and Smith, A. (2014) Hedging and Speculative Trading in Agricultural Futures Markets. *American Journal of Agricultural Economics* 96(2): 542-556.

Fisher, M. (2002) Special Repo Rates: An Introduction. *Federal Reserve Bank of Atlanta, Economic Review* 87(2): 27-43.

Fisher, G., Shah, R. and Titman, S. (2016) Combining Value and Momentum. *Journal of Investment Management* 14(2): 33-48.

Fisher, L. and Weil, R.L. (1971) Coping with the Risk of Interest-Rate Fluctuations: Returns to Bondholders from Naïve and Optimal Strategies. *Journal of Business* 44(4): 408-431.

Fleckenstein, M. (2012) The Inflation-Indexed Bond Puzzle. *Working Paper.* Available online: `https://ssrn.com/abstract=2180251`.

Fleckenstein, M., Longstaff, F.A. and Lustig, H.N. (2013) Why Does the Treasury Issue TIPS? The TIPS-Treasury Bond Puzzle. *Journal of Finance* 69(5): 2151-2197.

Fleckenstein, M., Longstaff, F.A. and Lustig, H.N. (2017) Deflation Risk. *Review of Financial Studies* 30(8): 2719-2760.

Fleming, M.J. and Krishnan, N. (2012) The Microstructure of the TIPS Market. *Federal Reserve Bank of New York, Economic Policy Review* 18(1): 27-45.

Fleming, J., Ostdiek, B. and Whaley, R.E. (1995) Predicting stock market volatility: A new measure. *Journal of Futures Markets* 15(3): 265-302.

Fleming, M.J. and Sporn, J.R. (2013) Trading Activity and Price Transparency in the Inflation Swap Market. *Federal Reserve Bank of New York, Economic Policy Review* 19(1): 45-58.

Flint, E. and Maré, E. (2017) Fractional Black-Scholes option pricing, volatility calibration and implied Hurst exponents in South African context. *South African Journal of Economic and Management Sciences* 20(1): a1532.

Fong, H.G. and Vasicek, O.A. (1983). The tradeoff between return and risk in immunized portfolios. *Financial Analysts Journal* 39(5): 73-78.

Fong, H.G. and Vasicek, O.A. (1984) A Risk Minimizing Strategy for Portfolio Immunization. *Journal of Finance* 39(5): 1541-1546.

Fong, W.M. and Yong, L.H.M. (2005) Chasing trends: recursive moving average trading rules and internet stocks. *Journal of Empirical Finance* 12(1): 43-76.

Fontaine, J.-F. and Nolin, G. (2017) Measuring Limits of Arbitrage in Fixed-Income Markets. *Staff Working Paper*, No. 2017-44. Ottawa, Canada: Bank of Canada.

Fontana, A. (2010) The Persistent Negative CDS-Bond Basis during the 2007/08 Financial Crisis. *Working Paper.* Available online: http://www.unive.it/media/allegato/DIP/Economia/Working_papers/Working_papers_2010/WP_DSE_fontana_13_10.pdf.

Fontana, A. and Scheicher, M. (2016) An analysis of euro area sovereign CDS and their relation with government bonds. *Journal of Banking & Finance* 62: 126-140.

Fortin, M. and Khoury, N. (1984) Hedging Interest Rate Risks with Financial Futures. *Canadian Journal of Administrative Sciences* 1(2): 367-382.

Foster, G., Olsen, C. and Shevlin, T. (1984) Earnings releases, anomalies, and the behavior of security returns. *Accounting Review* 59(4): 574-603.

Foster, F.D. and Whiteman, C.H. (2002) Bayesian Cross Hedging: An Example from the Soybean Market. *Australian Journal of Management* 27(2): 95-122.

Frachot, A. (1996) A reexamination of the uncovered interest rate parity hypothesis. *Journal of International Money and Finance* 15(3): 419-437.

Frankel, J.A. (2006) The Effect of Monetary Policy on Real Commodity Prices. In: Campbell, J. (ed.) *Asset Prices and Monetary Policy.* Chicago, IL: University of Chicago Press, pp. 291-333.

Franken, J.R.V. and Parcell, J.L. (2003) Cash Ethanol Cross-Hedging Opportunities. *Journal of Agricultural and Applied Economics* 35(3): 509-516.

Frazzini, A. and Pedersen, L.H. (2014) Betting against Beta. *Journal of Financial Economics* 111(1): 1-25.

Frenkel, J.A. and Levich, R.M. (1975) Covered interest arbitrage: Unexploited profits? *Journal of Political Economy* 83(2): 325-338.

Frenkel, J.A. and Levich, R.M. (1981) Covered interest arbitrage in the 1970's. *Economics Letters* 8(3): 267-274.

Frey, R. and Backhaus, J. (2008) Pricing and Hedging of Portfolio Credit Derivatives with Interacting Default Intensities. *International Journal of Theoretical and Applied Finance* 11(6): 611-634.

Frey, R. and Backhaus, J. (2010) Dynamic hedging of synthetic CDO tranches with spread risk and default contagion. *Journal of Economic Dynamics and Control* 34(4): 710-724.

Frey, R., McNeil, A. and Nyfeler, N. (2001) Copulas and Credit Models. *Risk*, October 2001, pp. 111-114.

Fridson, M.S. and Xu, X. (2014) Duration Targeting: No Magic for High-Yield Investors. *Financial Analysts Journal* 70(3): 28-33.

Friewald, N., Jankowitsch, R. and Subrahmanyam, M. (2012) Illiquidity, or Credit Deterioration: A Study of Liquidity in the U.S. Bond Market during Financial Crises. *Journal of Financial Economics* 105(1): 18-36.

Frino, A., Gallagher, D.R., Neubert, A.S. and Oetomo, T.N. (2004) Index Design and Implications for Index Tracking. *Journal of Portfolio Management* 30(2): 89-95.

Frino, A. and McKenzie, M. (2002) The pricing of stock index futures spreads at contract expiration. *Journal of Futures Markets* 22(5): 451-469.

Froot, K.A., Scharfstein, D.S. and Stein, J.C. (1993) Risk Management: Coordinating Corporate Investment and Financing Policies. *Journal of Finance* 48(5): 1629-1658.

Froot, K.A. and Thaler, R.H. (1990) Anomalies: Foreign Exchange. *Journal of Economic Perspectives* 4(3): 179-192.

Fry, J. and Cheah, E.T. (2016) Negative bubbles and shocks in cryptocurrency markets. *International Review of Financial Analysis* 47: 343-352.

Fu, F. (2009) Idiosyncratic Risk and the Cross-Section of Expected Stock Returns. *Journal of Financial Economics* 91(1): 24-37.

Fu, Y. and Qian, W. (2014) Speculators and Price Overreaction in the Housing Market. *Real Estate Economics* 42(4): 977-1007.

Fu, X., Sandri, M. and Shackleton, M.B. (2016) Asymmetric Effects of Volatility Risk on Stock Returns: Evidence from VIX and VIX Futures. *Journal of Futures Markets* 36(11): 1029-1056.

Fuertes, A., Miffre, J. and Fernandez-Perez, A. (2015) Commodity Strategies Based on Momentum, Term Structure, and Idiosyncratic Volatility. *Journal of Futures Markets* 35(3): 274-297.

Fuertes, A., Miffre, J. and Rallis, G. (2010) Tactical allocation in commodity futures markets: Combining momentum and term structure signals. *Journal of Banking & Finance* 34(10): 2530-2548.

Fugazza, C., Guidolin, M. and Nicodano, G. (2007) Investing for the Long-run in European Real Estate. *Journal of Real Estate Finance and Economics* 34(1): 35-80.

Fulli-Lemaire, N. (2013) An Inflation Hedging Strategy with Commodities: A Core Driven Global Macro. *Journal of Investment Strategies* 2(3): 23-50.

Fung, W. and Hsieh, D.A. (1999) A Primer on Hedge Funds. *Journal of Empirical Finance* 6(3): 309-331.

Fung, J.K.W., Mok, H.M.K. and Wong, K.C.K. (2004) Pricing Efficiency in a Thin Market with Competitive Market Makers: Box Spread Strategies in the Hang Seng Index Options Market. *Financial Review* 39(3): 435-454.

Fusaro, P.C. and James, T. (2005) *Energy Hedging in Asia: Market Structure and Trading Opportunities.* London, UK: Palgrave Macmillan.

Füss, R. and Nikitina, O. (2011) Explaining Yield Curve Dynamics. *Journal of Fixed Income* 21(2): 68-87.

Gabaix, X., Krishnamurthy, A. and Vigneron, O. (2007) Limits of arbitrage: theory and evidence from the mortgage-backed securities market. *Journal of Finance* 62(2): 557-595.

Gajardo, G., Kristjanpoller, W.D. and Minutolo, M. (2018) Does Bitcoin exhibit the same asymmetric multifractal cross-correlations with crude oil, gold and DJIA as the Euro, Great British Pound and Yen? *Chaos, Solitons & Fractals* 109: 195-205.

Gande, A., Altman, E. and Saunders, A. (2010) Bank Debt vs. Bond Debt: Evidence from Secondary Market Prices. *Journal of Money, Credit and Banking* 42(4): 755-767.

Gao, B. and Ren, R.-E. (2015) A New Sector Rotation Strategy and its Performance Evaluation: Based on a Principal Component Regression Model. *Working Paper.* Available online: https://ssrn.com/abstract=2628058.

Gao, C., Xing, Y. and Zhang, X. (2017) Anticipating Uncertainty: Straddles Around Earnings Announcements. *Working Paper.* Available online: https://ssrn.com/abstract=2204549.

Garbade, K.D. (2004) Origins of the Federal Reserve Book-Entry System. *Federal Reserve Bank of New York, Economic Policy Review* 10(3): 33-50.

Garcia, C.B. and Gould, F.J. (1993) Survivorship Bias. *Journal of Portfolio Management* 19(3): 52-56.

Garcia, D. and Schweitzer, F. (2015) Social signals and algorithmic trading of Bitcoin. *Royal Society Open Science* 2(9): 150288.

Garcia, D., Tessone, C.J., Mavrodiev, P. and Perony, N. (2014) The digital traces of bubbles: feedback cycles between socioeconomic signals in the Bitcoin economy. *Journal of The Royal Society Interface* 11(99): 0623.

Garcia-Feijóo, L., Kochard, L., Sullivan, R.N. and Wang, P. (2015) Low-Volatility Cycles: The Influence of Valuation and Momentum on Low-Volatility Portfolios. *Financial Analysts Journal* 71(3): 47-60.

Garlappi, L. and Yan, H. (2011) Financial Distress and the Cross-section of Equity Returns. *Journal of Finance* 66(3): 789-822.

Gârleanu, N., Pedersen, L.H. and Poteshman, A.M. (2009) Demand-Based Option Pricing. *Review of Financial Studies* 22(10): 4259-4299.

Garvey, R. and Wu, F. (2009) Intraday time and order execution quality dimensions. *Journal of Financial Markets* 12(2): 203-228.

Garyn-Tal, S. (2014a) An Investment Strategy in Active ETFs. *Journal of Index Investing* 4(1): 12-22.

Garyn-Tal, S. (2014b) Explaining and Predicting ETFs Alphas: The R^2 Methodology. *Journal of Index Investing* 4(4): 19-32.

Garzarelli, F., Cristelli, M., Pompa, G., Zaccaria, A. and Pietronero, L. (2014) Memory effects in stock price dynamics: evidences of technical trading. *Scientific Reports* 4: 4487.

Gatev, E., Goetzmann, W.N. and Rouwenhorst, K.G. (2006) Pairs Trading: Performance of a Relative-Value Arbitrage Rule. *Review of Financial Studies* 19(3): 797-827.

Gatheral, J. and Jacquier, A. (2014) Arbitrage-free SVI volatility surfaces. *Quantitative Finance* 14(1): 59-71.

Gatzlaff, D.H. and Tirtiroglu, D. (1995) Real Estate Market Efficiency: Issues and Evidence. *Journal of Real Estate Literature* 3(2): 157-189.

Gay, G.D. and Kolb, R.W. (1983) The Management of Interest Rate Risk. *Journal of Portfolio Management* 9(2): 65-70.

Gay, G.D., Kolb, R.W. and Chiang, R. (1983) Interest Rate Hedging: An Empirical Test Of Alternative Strategies. *Journal of Financial Research* 6(3): 187-197.

Ge, W. (2016) A Survey of Three Derivative-Based Methods to Harvest the Volatility Premium in Equity Markets. *Journal of Investing* 25(3): 48-58.

Géczy, C., Minton, B.A. and Schrand, C. (1997) Why Firms Use Currency Derivatives. *Journal of Finance* 52(4): 1323-1354.

Géczy, C.C. and Samonov, M. (2016) Two Centuries of Price-Return Momentum. *Financial Analysts Journal* 72(5): 32-56.

Gehricke, S.A. and Zhang, J.E. (2018) Modeling VXX. *Journal of Futures Markets* 38(8): 958-976.

Geltner, D.M., Miller, N.G., Clayton, J. and Eichholtz, P. (2006) *Commercial Real Estate Analysis and Investments.* (2nd ed.) Atlanta, GA: OnCourse Learning Publishing.

Geltner, D.M., Rodriguez, J.V. and O'Connor, D. (1995) The Similar Genetics of Public and Private Real Estate and the Optimal Long-Horizon Portfolio Mix. *Real Estate Finance* 12(3): 13-25.

Geman, H. (1998) *Insurance and Weather Derivatives: From Exotic Options to Exotic Underlyings.* London, UK: Risk Books.

Geman, H. and Leonardi, M.-P. (2005) Alternative approaches to weather derivatives pricing. *Managerial Finance* 31(6): 46-72.

Geman, H. and Roncoroni, A. (2006) Understanding the fine structure of electricity prices. *Journal of Business* 79(3): 1225-1261.

Gençay, R. (1996) Nonlinear prediction of security returns with moving average rules. *Journal of Forecasting* 15(3): 165-174.

Gençay, R. (1998) The Predictability of securities returns with simple technical rules. *Journal of Empirical Finance* 5(4): 347-359.

Gençay, R. and Stengos, T. (1998) Moving average rules, volume and the predictability of security returns with feedforward networks. *Journal of Forecasting* 17(5-6): 401-414.

Genesove, D. and Han, L. (2012) Search and Matching in the Housing Market. *Journal of Urban Economics* 72(1): 31-35.

Genesove, D. and Mayer, C. (1997) Equity and Time to Sale in the Real Estate Market. *American Economic Review* 87(3): 255-269.

Genesove, D. and Mayer, C. (2001) Loss Aversion and Seller Behavior: Evidence From the Housing Market. *Quarterly Journal of Economics* 116(4): 1233-1260.

George, T.J. and Hwang, C.-Y. (2010) A resolution of the distress risk and leverage puzzles in the cross section of stock returns. *Journal of Financial Economics* 96(1): 56-79.

Georgoula, I., Pournarakis, D., Bilanakos, C., Sotiropoulos, D. and Giaglis, G.M. (2015) Using Time-Series and Sentiment Analysis to Detect the Determinants of Bitcoin Prices. *Working Paper.* Available online: `https://ssrn.com/abstract=2607167`.

Gerakos, J. and Linnainmaa, J. (2012) Decomposing Value. *Working Paper.* Available online: `https://ssrn.com/abstract=2083166`.

Gervais, S. and Odean, T. (2001) Learning to Be Overconfident. *Review of Financial Studies* 14(1): 1-27.

Geske, R.L. and Pieptea, D.R. (1987) Controlling Interest Rate Risk and Return with Futures. *Review of Futures Markets* 6(1): 64-86.

Gestel, T., Suykens, J.A.K., Baestaend, D.E., Lambrechts, A., Lanckriet, G., Vandaele, B., Moor, B. and Vandewalle, J. (2001) Financial time series prediction using least squares support vector machines within the evidence framework. *IEEE Transactions on Neural Networks* 12(4): 809-821.

Ghiulnara, A. and Viegas, C. (2010) Introduction of weather-derivative concepts: perspectives for Portugal. *Journal of Risk Finance* 11(1): 9-19.

Ghosh, A. (1993) Hedging with stock index futures: Estimation and forecasting with error correction model. *Journal of Futures Markets* 13(7): 743-752.

Ghosh, A. (2012) Comparative study of Financial Time Series Prediction by Artificial Neural Network with Gradient Descent Learning. *International Journal of Scientific & Engineering Research* 3(1): 41-49.

Gibson, M.S. (2004) Understanding the Risk of Synthetic CDOs. *Finance and Economics Discussion Series (FEDS)*, Paper No. 2004-36. Washington, DC: Board of Governors of the Federal Reserve System. Available online: `https://www.federalreserve.gov/pubs/feds/2004/200436/200436pap.pdf`.

Gibson, M.S. and Pritsker, M. (2000) Improving Grid-based Methods for Estimating Value at Risk of Fixed-Income Portfolios. *Journal of Risk* 3(2): 65-89.

Gibson, R. and Schwartz, E.S. (1990) Stochastic convenience yield and the pricing of oil contingent claims. *Journal of Finance* 15(3): 959-967.

Giese, P. (2012) Optimal design of volatility-driven algo-alpha trading strategies. *Risk* 25(5): 68-73.

Giesecke, K. and Weber, S. (2006) Credit contagion and aggregate losses. *Journal of Economic Dynamics and Control* 30(5): 741-767.

Gilbert, S., Jones, S.K. and Morris, G.H. (2006) The impact of skewness in the hedging decision. *Journal of Futures Markets* 26(5): 503-520.

Gilmour, N. and Ridley, N. (2015) Everyday vulnerabilities – money laundering through cash intensive businesses. *Journal of Money Laundering Control* 18(3): 293-303.

Gilson, S.C. (1995) Investing in Distressed Situations: A Market Survey. *Financial Analysts Journal* 51(6): 8-27.

Gilson, S.C. (2010) *Creating Value Through Corporate Restructuring: Case Studies in Bankruptcies, Buyouts, and Breakups.* Hoboken, NJ: John Wiley & Sons, Inc.

Gilson, S. (2012) Preserving Value by Restructuring Debt. *Journal of Applied Corporate Finance* 24(4): 22-35.

Gilson, S.C., John, K. and Lang, L.H.P. (1990) Troubled debt restructurings: An empirical study of private reorganization of firms in default. *Journal of Financial Economics* 27(2): 315-353.

Girma, P.B. and Paulson, A.S. (1998) Seasonality in petroleum futures spreads. *Journal of Futures Markets* 18(5): 581-598.

Glabadanidis, P. (2015) Market Timing With Moving Averages. *International Review of Finance* 15(3): 387-425.

Glaeser, E.L. and Kallal, H.D. (1997) Thin Markets, Asymmetric Information, and Mortgage-Backed Securities. *Journal of Financial Intermediation* 6(1): 64-86.

Glasserman, P. and Wu, Q. (2010) Forward and future implied volatility. *International Journal of Theoretical and Applied Finance* 14(3): 407-432.

Gliner, G. (2014) *Global Macro Trading: Profiting in a New World Economy.* Hoboken, NJ: John Wiley & Sons, Inc.

Glorot, X., Bordes, A. and Bengio, Y. (2011) Deep Sparse Rectifier Neural Networks. *Proceedings of Machine Learning Research* 15: 315-323.

Godfrey, C. and Brooks, C. (2015) The Negative Credit Risk Premium Puzzle: A Limits to Arbitrage Story. *Working Paper.* Available online: https://ssrn.com/abstract=2661232.

Goebel, P.R., Harrison, D.M., Mercer, J.M. and Whitby, R.J. (2013) REIT Momentum and Characteristic-Related REIT Returns. *Journal of Real Estate Finance and Economics* 47(3): 564-581.

Goetzmann, W.N. and Ibbotson, R.G. (1990) The Performance of Real Estate as an Asset Class. *Journal of Applied Corporate Finance* 3(1): 65-76.

Goetzmann, W.N. and Ibbotson, R.G. (1994) Do Winners Repeat? *Journal of Portfolio Management* 20(2): 9-18.

Golden, L.L., Wang, M. and Yang, C. (2007) Handling Weather Related Risks through the Financial Markets: Considerations of Credit Risk, Basis Risk, and Hedging. *Journal of Risk and Insurance* 74(2): 319-346.

Goldstein, H.N. (1964) The Implications of Triangular Arbitrage for Forward Exchange Policy. *Journal of Finance* 19(3): 544-551.

Goltz, F. and Lai, W.N. (2009) Empirical properties of straddle returns. *Journal of Derivatives* 17(1): 38-48.

Göncü, A. (2012) Pricing temperature-based weather derivatives in China. *Journal of Risk Finance* 13(1): 32-44.

Goodfellow, I., Warde-Farley, D., Mirza, M., Courville, A. and Bengio, Y. (2013) Maxout Networks. *Proceedings of Machine Learning Research* 28(3): 1319-1327.

Goodfriend, M. (2011) Money Markets. *Annual Review of Financial Economics* 3: 119-1137.

Goodman, L.S. (2002) Synthetic CDOs: An Introduction. *Journal of Derivatives* 9(3): 60-72.

Goodman, L.S. and Lucas, D.J. (2002) And When CDOs PIK? *Journal of Fixed Income* 12(1): 96-102.

Gordini, N. (2014) A genetic algorithm approach for SMEs bankruptcy prediction: Empirical evidence from Italy. *Expert Systems with Applications* 41(14): 6433-6455.

Gorton, G.B., Hayashi, F. and Rouwenhorst, K.G. (2013) The Fundamentals of Commodity Futures Returns. *Review of Finance* 17(1): 35-105.

Gorton, G. and Metrick, A. (2012) Securitized banking and the run on repo. *Journal of Financial Economics* 104(3): 425-451.

Gorton, G.B. and Rouwenhorst, K.G. (2006) Facts and Fantasies about Commodity Futures. *Financial Analysts Journal* 62(2): 47-68.

Gradojevic, N., Gençay, R. and Erdemlioglu, D. (2017) Robust Prediction of Triangular Currency Arbitrage with Liquidity and Realized Risk Measures: A New Wavelet-Based Ultra-High-Frequency Analysis. *Working Paper.* Available online: https://ssrn.com/abstract=3018815.

Graff, R., Harrington, A. and Young, M. (1999) Serial Persistence in Disaggregated Australian Real Estate Returns. *Journal of Real Estate Portfolio Management* 5(2): 113-128.

Graff, R.A. and Young, M.S. (1997) Serial Persistence in Equity REIT Returns. *Journal of Real Estate Research* 14(3): 183-214.

Graham, M., Nikkinen, J. and Sahlström, P. (2003) Relative importance of scheduled macroeconomic news for stock market investors. *Journal of Economics and Finance* 27(2): 153-165.

Graham, S. and Pirie, W. (1994) Index Fund Rebalancing and Market Efficiency. *Journal of Economics and Finance* 18(2): 219-229.

Grant, J. (2016) *Trading Strategies in Futures Markets* (Ph.D. Thesis). London, UK: Imperial College. Available online: https://spiral.imperial.ac.uk/bitstream/10044/1/32011/1/Grant-J-2016-PhD-Thesis.PDFA.pdf.

Grantier, B.J. (1988) Convexity and Bond Performance: The Benter the Better. *Financial Analysts Journal* 44(6): 79-81.

Grasselli, M. and Wagalath, L. (2018) VIX vs VXX: A Joint Analytical Framework. *Working Paper.* Available online: https://ssrn.com/abstract=3144526.

Green, R.C. and Rydqvist, K. (1999) Ex-day behavior with dividend preference and limitations to short-term arbitrage: the case of Swedish lottery bonds. *Journal of Financial Economics* 53(2): 145-187.

Greenhaus, S.F. (1991) Approaches to Investing in Distressed Securities: Passive Approaches. In: Bowman, T.A. (ed.) *Analyzing Investment Opportunities in Distressed and Bankrupt Companies.* (AIMR Conference Proceedings, Vol. 1991, Iss. 1.) Chicago, IL: AIMR, pp. 47-52.

Greer, R.J. (1978) Conservative Commodities: A Key Inflation Hedge. *Journal of Portfolio Management* 4(4): 26-29.

Greer, R.J. (2000) The Nature of Commodity Index Returns. *Journal of Alternative Investments* 3(1): 45-52.

Greer, R.J. (2007) The Role of Commodities in Investment Portfolios. *CFA Institute Conference Proceedings Quarterly* 24(4): 35-44.

Grieves, R. (1999) Butterfly Trades. *Journal of Portfolio Management* 26(1): 87-95.

Grieves, R. and Mann, S.V. (2004) An Overlooked Coupon Effect in Treasury Futures Contracts. *Journal of Derivatives* 12(2): 56-61.

Grieves, R., Mann, S.V., Marcus, A.J. and Ramanlal, P. (1999) Riding the Bill Curve. *Journal of Portfolio Management* 25(3): 74-82.

Grieves, R. and Marcus, A.J. (1992) Riding the Yield Curve: Reprise. *Journal of Portfolio Management* 18(4): 67-76.

Grieves, R. and Marcus, A.J. (2005) Delivery Options and Treasury-Bond Futures Hedge Ratios. *Journal of Derivatives* 13(2): 70-76.

Griffin, J.M., Ji, X. and Martin, J.S. (2003) Momentum Investing and Business Cycle Risks: Evidence from Pole to Pole. *Journal of Finance* 58(6): 2515-2547.

Griffin, J.M. and Lemmon, M.L. (2002) Book-to-Market Equity, Distress Risk, and Stock Returns. *Journal of Finance* 57(5): 2317-2336.

Grigg, N.S. (2010) *Infrastructure Finance: The Business of Infrastructure for a Sustainable Future.* Hoboken, NJ: John Wiley & Sons, Inc.

Grimsey, D. and Lewis, M.K. (2002) Evaluating the risks of public private partnerships for infrastructure projects. *International Journal of Project Management* 20(2): 107-118.

Grinblatt, M. and Moskowitz, T.J. (2004) Predicting Stock Price Movements from Past Returns: The Role of Consistency and Tax-Loss Selling. *Journal of Financial Economics* 71(3): 541-579.

Grinblatt, M. and Titman, S. (1992) The Persistence of Mutual Fund Performance. *Journal of Finance* 47(5): 1977-1984.

Grinold, R.C. and Kahn, R.N. (2000) *Active Portfolio Management.* New York, NY: McGraw-Hill, Inc.

Grishchenko, O.V. and Huang, J.-Z. (2013) Inflation Risk Premium: Evidence from the TIPS Market. *Journal of Fixed Income* 22(4): 5-30.

Grishchenko, O.V., Vanden, J.M. and Zhang, J. (2016) The Informational Content of the Embedded Deflation Option in TIPS. *Journal of Banking & Finance* 65: 1-26.

Grissom, T.V., Kuhle, J.L. and Walther, C.H. (1987) Diversification works in real estate, too. *Journal of Portfolio Management* 13(2): 66-71.

Grobys, K., Heinonen, J.-P. and Kolari, J.W. (2016) Is Currency Momentum a Hedge for Global Economic Risk? *Working Paper.* Available online: https://ssrn.com/abstract=2619146.

Grudnitski, G. and Osborn, L. (1993) Forecasting S&P and Gold Futures Prices: An Application of Neural Networks. *Journal of Futures Markets* 13(6): 631-643.

Grundy, B.D. and Martin, J.S. (2001) Understanding the Nature of the Risks and the Source of the Rewards to Momentum Investing. *Review of Financial Studies* 14(1): 29-78.

Grundy, B.D. and Verwijmeren, P. (2016) Disappearing call delay and dividend-protected convertible bonds. *Journal of Finance* 71(1): 195-224.

Gunasekarage, A. and Power, D.M. (2001) The profitability of moving average trading rules in South Asian stock markets. *Emerging Markets Review* 2(1): 17-33.

Gunasekarage, A., Power, D.M. and Ting Zhou, T.T. (2008) The long-term inflation hedging effectiveness of real estate and financial assets: A New Zealand investigation. *Studies in Economics and Finance* 25(4): 267-278.

Guo, D. (2000) Dynamic Volatility Trading Strategies in the Currency Option Market. *Review of Derivatives Research* 4(2): 133-154.

Gupta, R. and Miller, S.M. (2012) "Ripple effects" and forecasting home prices in Los Angeles, Las Vegas, and Phoenix. *Annals of Regional Science* 48(3): 763-782.

Guren, A.M. (2014) The Causes and Consequences of House Price Momentum. *Working Paper.* Available online: http://scholar.harvard.edu/files/guren/files/gurenjmp.pdf.

Gürkaynak, R.S., Sack, B. and Wright, J.H. (2010) The TIPS Yield Curve and Inflation Compensation. *American Economic Journal: Macroeconomics* 2(1): 70-92.

Gutierrez, R.C. and Prinsky, C.A. (2007) Momentum, Reversal, and the Trading Behaviors of Institutions. *Journal of Financial Markets* 10(1): 48-75.

Hafner, R. and Wallmeier, M. (2007) Volatility as an Asset Class: European Evidence. *European Journal of Finance* 13(7): 621-644.

Hagenstein, F., Mertz, A. and Seifert, J. (2004) *Investing in Corporate Bonds and Credit Risk.* London, UK: Palgrave Macmillan.

Hagopian, G.C. (1999) Property-flipping and fraudulent appraisals: The phenomenon and the crackdown. *Assessment Journal* 6(6): 33-39.

Hagströmer, B. and Nordén, L. (2013) The Diversity of High-Frequency Traders. *Journal of Financial Markets* 16(4): 741-770.

Hagströmer, B., Nordén, L. and Zhang, D. (2014) The Aggressiveness of High-Frequency Traders. *Financial Review* 49(2): 395-419.

Hall, P., Park, B.U. and Samworth, R.J. (2008) Choice of neighbor order in nearest-neighbor classification. *Annals of Statistics* 36(5): 2135-2152.

Hall, J., Pinnuck, M. and Thorne, M. (2013) Market risk exposure of merger arbitrage in Australia. *Accounting & Finance* 53(1): 185-215.

Hamelink, F. and Hoesli, M. (1996) Swiss real estate as a hedge against inflation: New evidence using hedonic and autoregressive models. *Journal of Property Finance* 7(1): 33-49.

Hamerle, A., Igl, A. and Plank, K. (2012) Correlation smile, volatility skew, and systematic risk sensitivity of tranches. *Journal of Derivatives* 19(3): 8-27.

Hamilton, J. (2003) What is an oil shock? *Journal of Econometrics* 113(2): 363-398.

Hamisultane, H. (2009) Utility-based pricing of weather derivatives. *European Journal of Finance* 16(6): 503-525.

Han, S. and Qiu, J. (2007) Corporate precautionary cash holdings. *Journal of Corporate Finance* 13(1): 43-57.

Hancock, G.D. (2013) VIX Futures ETNs: Three Dimensional Losers. *Accounting and Finance Research* 2(3): 53-64.

Hanley, M. (1999) Hedging the Force of Nature. *Risk Professional* 5(4): 21-25.

Hanly, J., Morales, L. and Cassells, D. (2018) The efficacy of financial futures as a hedging tool in electricity markets. *International Journal of Financial Economics* 23(1): 29-40.

Hansch, O., Naik, N.Y. and Viswanathan, S. (1998) Do inventories matter in dealership markets? Evidence from the London stock exchange. *Journal of Finance* 53(5): 1623-1656.

Hansen, L.P. and Hodrick, R.J. (1980) Forward Exchange Rates as Optimal Predictors of Future Spot Rates: An Econometric Analysis. *Journal of Political Economy* 88(5): 829-853.

Happ, S. (1986) The Behavior of Rates on Federal Funds and Repurchase Agreements. *American Economist* 30(2): 22-32.

Haran, M., Newell, G., Adair, A., McGreal, S. and Berry, J. (2011) The performance of UK regeneration property within a mixed asset portfolio. *Journal of Property Research* 28(1): 75-95.

Harčariková, M. and Šoltés, M. (2016) Risk Management in Energy Sector Using Short Call Ladder Strategy. *Montenegrin Journal of Economics* 12(3): 39-54.

Härdle, W.K. and López Cabrera, B. (2011) The Implied Market Price of Weather Risk. *Applied Mathematical Finance* 19(1): 59-95.

Härdle, W. and Silyakova, E. (2010) Volatility Investing with Variance Swaps. *Working Paper.* Available online: https://ssrn.com/abstract=2894245.

Hardy, C.C. (1978) *The Investor's Guide to Technical Analysis.* New York, NY: McGraw-Hill, Inc.

Harford, J. (2005) What drives merger waves? *Journal of Financial Economics* 77(3): 529-560.

Harner, M.M. (2008) The Corporate Governance and Public Policy Implications of Activist Distressed Debt Investing. *Fordham Law Review* 77(2): 703-773.

Harner, M.M. (2011) Activist Distressed Debtholders: The New Barbarians at the Gate? *Washington University Law Review* 89(1): 155-206.

Harris, T.S., Hubbard, R.G. and Kemsley, D. (2001) The Share Price Effects Of Dividend Taxes And Tax Imputation Credits. *Journal of Public Economics* 79(3): 569-596.

Harris, L.E. and Namvar, E. (2016) The Economics of Flash Orders and Trading. *Journal of Investment Management* 14(4): 74-86.

Harris, R.D.F. and Yilmaz, F. (2009) A momentum trading strategy based on the low frequency component of the exchange rate. *Journal of Banking & Finance* 33(9): 1575-1585.

Harrison, J.M. and Pliska, S.R. (1981) Martingales and stochastic integrals in the theory of continuous trading. *Stochastic Processes and Their Applications* 11(3): 215-260.

Hartigan, L.R., Prasad, R. and De Francesco, A.J. (2011) Constructing an investment return series for the UK unlisted infrastructure market: estimation and application. *Journal of Property Research* 28(1): 35-58.

Hartzell, D.J., Eichholtz, P. and Selender, A. (2007) Economic diversification in European real estate portfolios. *Journal of Property Research* 10(1): 5-25.

Hartzell, D., Hekman, J. and Miles, M. (1986) Diversification Categories in Investment Real Estate. *Real Estate Economics* 14(2): 230-254.

Hartzell, D., Hekman, J.S. and Miles, M.E. (1987) Real Estate Returns and Inflation. *Real Estate Economics* 15(1): 617-637.

Hartzell, D.J., Shulman, D.G. and Wurtzebach, C.H. (1987) Refining the Analysis of Regional Diversification for Income-Producing Real Estate. *Journal of Real Estate Research* 2(2): 85-95.

Hartzog, J. (1982) Controlling Profit Volatility: Hedging with GNMA Options. *Federal Home Loan Bank Board Journal* 15(2): 10-14.

Harvey, A.C. (1984) A unified view of statistical forecasting procedures. *Journal of Forecasting* 3(3): 245-275.

Harvey, A.C. (1990) *Forecasting, Structural Time Series Models and the Kalman Filter.* Cambridge, UK: Cambridge University Press.

Harvey, C.R. (2014) Bitcoin Myths and Facts. *Working Paper.* Available online: `https://ssrn.com/abstract=2479670`.

Harvey, C.R. (2016) Cryptofinance. *Working Paper.* Available online: `https://ssrn.com/abstract=2438299`.

Harvey, J.T. (2015) Deviations from uncovered interest rate parity: a Post Keynesian explanation. *Journal of Post Keynesian Economics* 27(1): 19-35.

Harvey, A. and Trimbur, T. (2008) Trend Estimation and the Hodrick-Prescott Filter. *Journal of the Japan Statistical Society* 38(1): 41-49.

Hasbrouck, J. and Saar, G. (2013) Low-latency Trading. *Journal of Financial Markets* 16(4): 646-679.

Hastings, A. and Nordby, H. (2007) Benefits of Global Diversification on a Real Estate Portfolio. *Journal of Portfolio Management* 33(5): 53-62.

Hatemi-J, A. and Roca, E. (2006) Calculating the optimal hedge ratio: constant, time varying and the Kalman Filter approach. *Applied Economics Letters* 13(5): 293-299.

Hau, H. (2014) The exchange rate effect of multi-currency risk arbitrage. *Journal of International Money and Finance* 47: 304-331.

Haubrich, J., Pennacchi, G. and Ritchken, P. (2012) Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps. *Review of Financial Studies* 25(5): 1588-1629.

Haug, E.G. (2001) Closed form Valuation of American Barrier Options. *International Journal of Theoretical and Applied Finance* 4(2): 355-359.

Haugen, R.A. (1995) *The New Finance: The Case Against Efficient Markets.* Upper Saddle River, NJ: Prentice Hall.

Haurin, D.R. and Gill, H.L. (2002) The Impact of Transaction Costs and the Expected Length of Stay on Homeownership. *Journal of Urban Economics* 51(3): 563-584.

Haurin, D.R., Haurin, J.L., Nadauld, T. and Sanders, A. (2010) List Prices, Sale Prices and Marketing Time: An Application to U.S. Housing Markets. *Real Estate Economics* 38(4): 659-685.

Hautcoeur, P.C. (2006) Why and how to measure stock market fluctuations? The early history of stock market indices, with special reference to the French case. *Working Paper.* Available online: `https://halshs.archives-ouvertes.fr/halshs-00590522/PDF/wp200610.pdf`.

Hayes, B. (2011) Multiple time scale attribution for commodity trading advisor (CTA) funds. *Journal of Investment Management* 9(2): 35-72.

Hayre, L.S. (1990) Understanding option-adjusted spreads and their use. *Journal of Portfolio Management* 16(4): 68-69.

He, D.X., Hsu, J.C. and Rue, N. (2015) Option-Writing Strategies in a Low-Volatility Framework. *Journal of Investing* 24(3): 116-128.

He, J., Tang, Q. and Zhang, H. (2016) Risk reducers in convex order. *Insurance: Mathematics and Economics* 70: 80-88.

Head, A., Lloyd-Ellis, H. and Sun, H. (2014) Search, Liquidity, and the Dynamics of House Prices and Construction. *American Economic Review* 104(4): 1172-1210.

Heaton, H. (1988) On the possible tax-driven arbitrage opportunities in the new municipal bond futures contract. *Journal of Futures Markets* 8(3): 291-302.

Hegde, S.P. (1982) The Impact of Interest Rate Level and Volatility on the Performance of Interest Rate Hedges. *Journal of Futures Markets* 2(4): 341-356.

Heidari, M. and Wu, L. (2003) Are Interest Rate Derivatives Spanned by the Term Structure of Interest Rates? *Journal of Fixed Income* 13(1): 75-86.

Helm, D. (2009) Infrastructure Investment, the Cost of Capital, and Regulation: an Assessment. *Oxford Review of Economic Policy* 25(3): 307-326.

Helm, D. and Tindall, T. (2009) The Evolution of Infrastructure and Utility Ownership and its Implications. *Oxford Review of Economic Policy* 25(3): 411-434.

Hemler, M.L. and Miller, T.W., Jr. (1997) Box spread arbitrage profits following the 1987 market crash. *Journal of Financial and Quantitative Analysis* 32(1): 71-90.

Hemler, M.L. and Miller, T.W., Jr. (2015) The Performance of Options-Based Investment Strategies: Evidence for Individual Stocks During 2003-2013. *Working Paper.* Available online:
`http://www.optionseducation.org/content/dam/oic/documents/literature/files/perf-options-strategies.pdf`.

Hendershott, T., Jones, C. and Menkveld, A. (2011) Does Algorithmic Trading Improve Liquidity? *Journal of Finance* 66(1): 1-33.

Hendershott, T., Jones, C. and Menkveld, A. (2013) Implementation Shortfall with Transitory Price Effects. In: Easley, D., López de Prado, M. and O'Hara, M. (eds.) *High Frequency Trading: New Realities for Traders, Markets and Regulators.* London, UK: Risk Books, Chapter 9.

Hendershott, T. and Moulton, P.C. (2011) Automation, speed, and stock market quality: The NYSE's Hybrid. *Journal of Financial Markets* 14(4): 568-604.

Hendershott, T. and Riordan, R. (2013) Algorithmic Trading and the Market for Liquidity. *Journal of Financial and Quantitative Analysis* 48(4): 1001-1024.

Henderson, B. (2005) *Convertible Bonds: New Issue Performance and Arbitrage Opportunities* (Ph.D. Thesis). Urbana-Champaign IL: University of Illinois.

Henderson, R. (1924) A new method of graduation. *Transactions of the Actuarial Society of America* 25: 29-40.

Henderson, R. (1925) Further remarks on graduation. *Transactions of the Actuarial Society of America* 26: 52-57.

Henderson, R. (1938) *Mathematical Theory of Graduation.* New York, NY: Actuarial Society of America.

Henderson, T.M. (2003) *Fixed Income Strategy: The Practitioner's Guide to Riding the Curve.* Chichester, UK: John Wiley & Sons, Ltd.

Henderson, B.J. and Tookes, H. (2012) Do investment banks' relationships with investors impact pricing? The case of convertible bond issues. *Management Science* 58(2): 2272-2291.

Henrard, M.P.A. (2006) A Semi-Explicit Approach to Canary Swaptions in HJM One-Factor Model. *Applied Mathematical Finance* 13(1): 1-18.

Hensher, D. and Jones, S. (2007) Forecasting corporate bankruptcy: Optimizing the performance of the mixed logit model. *Abacus* 43(3): 241-364.

Herbertsson, A. (2008) Pricing synthetic CDO tranches in a model with default contagion using the matrix-analytic approach. *Journal of Credit Risk* 4(4): 3-35.

Herranz-Loncán, A. (2007) Infrastructure investment and Spanish economic growth, 1850-1935. *Explorations in Economic History* 44(3): 452-468.

Hess, D., Huang, H. and Niessen, A. (2008) How Do Commodity Futures Respond to Macroeconomic News? *Financial Markets and Portfolio Management* 22(2): 127-146.

Hew, D., Skerratt, L., Strong, N. and Walker, M. (1996) Post-earnings-announcement drift: Some preliminary evidence for the UK. *Accounting & Business Research* 26(4): 283-293.

Hill, J.M., Balasubramanian, V., Gregory, K. and Tierens, I. (2006) Finding Alpha via Covered Call Writing. *Financial Analysts Journal* 62(5): 29-46.

Hill, J.M., Nadig, D. and Hougan, M. (2015) A Comprehensive Guide to Exchange-Traded Funds (ETFs). *Research Foundation Publications* 2015(3): 1-181.

Hillegeist, S.A., Keating, E., Cram, D.P. and Lunstedt, K.G. (2004) Assessing the probability of bankruptcy. *Review of Accounting Studies* 9(1): 5-34.

Hilliard, J.E. (1984) Hedging Interest Rate Risk with Futures Portfolios under Term Structure Effects. *Journal of Finance* 39(5): 1547-1569.

Hilliard, J. and Jordan, S. (1989) Hedging Interest Rate Risk with Futures Portfolios under Full-Rank Assumptions. *Journal of Financial and Quantitative Analysis* 24(2): 217-240.

Hilliard, J. and Reis, J. (1998) Valuation of commodity futures and options under stochastic convenience yields, interest rates, and jump diffusions on the spot. *Journal of Financial and Quantitative Analysis* 33(1): 61-86.

Hinnerich, M. (2008) Inflation-indexed swaps and swaptions. *Journal of Banking & Finance* 32(11): 2293-2306.

Hirschey, N. (2018) Do High-Frequency Traders Anticipate Buying and Selling Pressure? *Working Paper.* Available online: https://ssrn.com/abstract=2238516.

Hirshleifer, D. (1990) Hedging Pressure and Futures Price Movements in a General Equilibrium Model. *Econometrica* 58(2): 411-428.

Hirshleifer, D., Lim, S.S. and Teoh, S.H. (2009) Driven to distraction: Extraneous events and underreaction to earnings news. *Journal of Finance* 64(5): 2289-2325.

Ho, T. and Saunders, A. (1983) Fixed Rate Loan Commitments, Take-Down Risk, and the Dynamics of Hedging with Futures. *Journal of Financial and Quantitative Analysis* 18(4): 499-516.

Hodges, S. and Carverhill, A. (1993) Quasi mean reversion in an efficient stock market: the characterization of economic equilibria which support Black-Scholes option pricing. *Economic Journal* 103(417): 395-405.

Hodrick, R.J. (1987) *The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets.* New York, NY: Harwood Academic.

Hodrick, R.J. and Prescott, E.C. (1997) Postwar U.S. Business Cycles: An Empirical Investigation. *Journal of Money, Credit and Banking* 29(1): 1-16.

Hoesli, M. and Lekander, J. (2008) Real estate portfolio strategy and product innovation in Europe. *Journal of Property Investment & Finance* 26(2): 162-176.

Hoevenaars, R.P.M.M., Molenaar, R.D.J., Schotman, P.C. and Steenkamp, T.B.M. (2008) Strategic asset allocation with liabilities: Beyond stocks and bonds. *Journal of Economic Dynamics and Control* 32(9): 2939-2970.

Holden, C.W. and Jacobsen, S. (2014) Liquidity Measurement Problems in Fast Competitive Markets: Expensive and Cheap Solutions. *Journal of Finance* 69(4): 1747-1885.

Holmes, P. (1996) Stock index futures hedging: hedge ratio estimation, duration effects, expiration effects and hedge ratio stability. *Journal of Business Finance & Accounting* 23(1): 63-77.

Hong, H., Torous, W. and Valkanov, R. (2007) Do Industries Lead Stock Markets? *Journal of Financial Economics* 83(2): 367-396.

Hopton, D. (1999) Prevention of Money Laundering: The Practical Day-to-Day Problems and Some Solutions. *Journal of Money Laundering Control* 2(3): 249-252.

Hördahl, P. and Tristani, O. (2012) Inflation Risk Premia in the Term Structure of Interest Rates. *Journal of the European Economic Association* 10(3): 634-657.

Hördahl, P. and Tristani, O. (2014) Inflation Risk Premia in the Euro Area and the United States. *International Journal of Central Banking* 10(3): 1-47.

Horvath, P.A. (1998) A Measurement of the Errors in Intra-Period Compounding and Bond Valuation: A Short Extension. *Financial Review* 23(3): 359-363.

Hotchkiss, E.S. and Mooradian, R.M. (1997) Vulture Investors and the Market for Control of Distressed Firms. *Journal of Financial Economics* 43(3): 401-432.

Hotchkiss, E.S. and Ronen, R. (2002) The Informational Efficiency of the Corporate Bond Market: An Intraday Analysis. *Review of Financial Studies* 15(5): 1325-1354.

Hou, A.J. and Nordén, L.L. (2018) VIX futures calendar spreads. *Journal of Futures Markets* 38(7): 822-838.

Houdain, J.P. and Guegan, D. (2006) Hedging tranches index products: illustration of model dependency. *ICFAI Journal of Derivatives Markets* 4: 39-61.

Houweling, P. and van Vundert, J. (2017) Factor Investing in the Corporate Bond Market. *Financial Analysts Journal* 73(2): 100-115.

Howison, S.D., Reisinger, C. and Witte, J.H. (2013) The Effect of Nonsmooth Payoffs on the Penalty Approximation of American Options. *SIAM Journal on Financial Mathematics* 4(1): 539-574.

Hsieh, C.H. and Barmish, B.R. (2015) On Kelly betting: Some limitations. In: *Proceeding of the 53rd Annual Allerton Conference on Communication, Control, and Computing.* Washington, DC: IEEE, pp. 165-172.

Hsieh, C.H., Barmish, B.R. and Gubner, J.A. (2016) Kelly betting can be too conservative. In: *Proceedings of the 2016 Conference on Decision and Control (CDC).* Washington, DC: IEEE, pp. 3695-3701.

Hsieh, J. and Walkling, R.A. (2005) Determinants and Implications of Arbitrage Holdings in Acquisitions. *Journal of Financial Economics* 77(3): 605-648.

Hsu, M. (1998) Spark Spread Options Are Hot! *Electricity Journal* 11(2): 28-39.

Hsu, Y.-C., Lin, H.-W. and Vincent, K. (2018) Analyzing the Performance of Multi-Factor Investment Strategies under Multiple Testing Framework. *Working Paper.* Available online:
`http://www.econ.sinica.edu.tw/UpFiles/2013092817175327692/Seminar_PDF2013093010102890633/17-A0001(all).pdf`.

Hu, J. (2001) *Basics of Mortgage-Backed Securities.* (2nd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Huang, J-.Z. and Kong, W. (2003) Explaining Credit Spread Changes: New Evidence From Option-Adjusted Bond Indexes. *Journal of Derivatives* 11(1): 30-44.

Huang, W., Nakamori, Y. and Wang, S.-Y. (2005) Forecasting stock market movement direction with support vector machine. *Computers & Operation Research* 32(10): 2513-2522.

Huang, H., Shiu, Y. and Lin, P. (2008) HDD and CDD option pricing with market price of weather risk for Taiwan. *Journal of Futures Markets* 28(8): 790-814.

Huang, C.L. and Tsai, C.Y. (2009) A hybrid SOFM-SVR with a filter-based feature selection for stock market forecasting. *Expert Systems with Applications* 36(2): 1529-1539.

Huault, I. and Rainelli-Weis, H. (2011) A Market for Weather Risk? Conflicting Metrics, Attempts at compromise, and Limits to Commensuration. *Organization Studies* 32(10): 1395-1419.

Huck, N. (2009) Pairs selection and outranking: An application to the S&P 100 index. *European Journal of Operational Research* 196(2): 819-825.

Huck, N. (2015) Pairs trading: Does volatility timing matter? *Applied Economics* 47(57): 6239-6256.

Huck, N. and Afawubo, K. (2014) Pairs trading and selection methods: is cointegration superior? *Applied Economics* 47(6): 599-613.

Hudson-Wilson, S. (1990) New Trends in Portfolio Theory. *Journal of Property Management* 55(3): 57-58.

Hudson-Wilson, S., Gordon, J.N., Fabozzi, F.J., Anson, M.J.P. and Giliberto, M. (2005) Why Real Estate? *Journal of Portfolio Management* 31(5): 12-21.

Huerta, R., Elkan, C. and Corbacho, F. (2013) Nonlinear Support Vector Machines Can Systematically Identify Stocks with High and Low Future Returns. *Algorithmic Finance* 2(1): 45-58.

Hühn, H. and Scholz, H. (2017) Alpha Momentum and Price Momentum. *Working Paper.* Available online: https://ssrn.com/abstract=2287848.

Huij, J. and Lansdorp, S. (2017) Residual Momentum and Reversal Strategies Revisited. *Working Paper.* Available online: https://ssrn.com/abstract=2929306.

Hull, D.A. (1996) Stemming algorithms: A case study for detailed evaluation. *Journal of the American Society for Information Science and Technology* 47(1): 70-84.

Hull, J.C. (2012) *Options, Futures and Other Derivatives.* Upper Saddle River, NJ: Prentice Hall.

Hull, J.C. and White, A.D. (2004) Valuation of a CDO and an n^{th} to Default CDS without Monte Carlo Simulation. *Journal of Derivatives* 12(2): 8-23.

Hull, J.C. and White, A.D. (2006) Valuing Credit Derivatives Using an Implied Copula Approach. *Journal of Derivatives* 14(2): 8-28.

Hull, J.C. and White, A.D. (2010) An Improved Implied Copula Model and its Application to the Valuation of Bespoke CDO Tranches. *Journal of Investment Management* 8(3): 11-31.

Hull, J., Predescu, M. and White, A. (2005) Bond Prices, Default Probabilities and Risk Premiums. *Journal of Credit Risk* 1(2): 53-60.

Hung, N.H. (2016) Various moving average convergence divergence trading strategies: a comparison. *Investment Management and Financial Innovations* 13(2): 363-369.

Hunter, R. (1999) Managing Mother Nature. *Derivatives Strategy* 4(2): 15-19.

Hunter, D.M. and Simon, D.P. (2005) Are TIPS the "real" deal?: A conditional assessment of their role in a nominal portfolio. *Journal of Banking & Finance* 29(2): 347-368.

Hürlimann, W. (2002) On immunization, stop-loss order and the maximum Shiu measure. *Insurance: Mathematics and Economics* 31(3): 315-325.

Hürlimann, W. (2012) On directional immunization and exact matching. *Communications in Mathematical Finance* 1(1): 1-12

Hurst, B., Ooi, Y.H. and Pedersen, L.H. (2017) A Century of Evidence on Trend-Following Investing. *Journal of Portfolio Management* 44(1): 15-29.

Husson, T. and McCann, C.J. (2011) The VXX ETN and Volatility Exposure. *PIABA Bar Journal* 18(2): 235-252.

Hutson, E. (2000) Takeover targets and the probability of bid success: Evidence from the Australian market. *International Review of Financial Analysis* 9(1): 45-65.

Hwang, C.-Y. and George, T.J. (2004) The 52-Week High and Momentum Investing. *Journal of Finance* 59(5): 2145-2176.

Idzorek, T. (2007) A Step-by-Step Guide to the Black-Litterman Model. In: Satchell, S. (ed.) *Forecasting Expected Returns in the Financial Markets.* Waltham, MA: Academic Press.

Illueca, M. and Lafuente, J.A. (2003) The Effect of Spot and Futures Trading on Stock Index Volatility: A Non-parametric Approach. *Journal of Futures Markets* 23(9): 841-858.

Ilmanen, A. (2011) *Expected Returns: An Investor's Guide to Harvesting Market Rewards.* Hoboken, NJ: John Wiley & Sons, Inc.

Ilmanen, A., Byrne, R., Gunasekera, H. and Minikin, R. (2004) Which Risks Have Been Best Rewarded? *Journal of Portfolio Management* 30(2): 53-57.

Ilut, C. (2012) Ambiguity Aversion: Implications for the Uncovered Interest Rate Parity Puzzle. *American Economic Journal: Macroeconomics* 4(3): 33-65.

Inderst, G. (2010a) Infrastructure as an Asset Class. *EIB Papers* 15(1): 70-105.

Inderst, G. (2010b) Pension fund investment in infrastructure: What have we learnt? *Pensions: An International Journal* 15(2): 89-99.

Ingersoll, J. (1977) A contingent-claims valuation of convertible securities. *Journal of Financial Economics* 4(3): 289-322.

Irwin, S.H., Zulauf, C.R. and Jackson, T.E. (1996) Monte Carlo analysis of mean reversion in commodity futures prices. *American Journal of Agricultural Economics* 78(2): 387-399.

Israelov, R. (2017) Pathetic Protection: The Elusive Benefits of Protective Puts. *Working Paper*. Available online: https://ssrn.com/abstract=2934538.

Israelov, R. and Klein, M. (2016) Risk and Return of Equity Index Collar Strategies. *Journal of Alternative Investments* 19(1): 41-54.

Israelov, R. and Nielsen, L.N. (2014) Covered Call Strategies: One Fact and Eight Myths. *Financial Analysts Journal* 70(6): 23-31.

Israelov, R. and Nielsen, L.N. (2015a) Covered Calls Uncovered. *Financial Analysts Journal* 71(6): 44-57.

Israelov, R. and Nielsen, L.N. (2015b) Still Not Cheap: Portfolio Protection in Calm Markets. *Journal of Portfolio Management* 41(4): 108-120.

Israelov, R., Nielsen L.N. and Villalon, D. (2017) Embracing Downside Risk. *Journal of Alternative Investments* 19(3): 59-67.

Ito, T., Yamada, K., Takayasu, M. and Takayasu, H. (2012) Free Lunch! Arbitrage Opportunities in the Foreign Exchange Markets. *Working Paper.* Available online: http://www.nber.org/papers/w18541.

Iturricastillo, I. and De La Peña, J.I. (2010) Absolute Immunization Risk as general measure of immunization risk. *Análisis Financiero* 114(3): 42-59.

Ivanov, I.T. and Lenkey, S.L. (2014) Are Concerns About Leveraged ETFs Overblown? *Finance and Economics Discussion Series (FEDS)*, Paper No. 2014-106. Washington, DC: Board of Governors of the Federal Reserve System. Available online: https://www.federalreserve.gov/econresdata/feds/2014/files/2014106pap.pdf.

Jabbour, G. and Budwick, P. (2010) *The option trader handbook: strategies and trade adjustments.* (2nd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Jackwerth, J.C. (2000) Recovering Risk Aversion from Option Prices and Realized Returns. *Review of Financial Studies* 13(2): 433-451.

Jacobs, H. and Weber, M. (2015) On the determinants of pairs trading profitability. *Journal of Financial Markets* 23: 75-97.

Jacoby, G. and Shiller, I. (2008) Duration and Pricing of TIPS. *Journal of Fixed Income* 18(2): 71-84.

Jain, G. and Baile, C. (2000) Managing weather risks. *Strategic Risk*, September 2000, pp. 28-31.

James, F.E., Jr. (1968) Monthly moving averages – An effective investment tool? *Journal of Financial and Quantitative Analysis* 3(3): 315-326.

James, T. (2003) *Energy Price Risk: Trading and Price Risk Management.* London, UK: Palgrave Macmillan.

Jan, T.C. and Hung, M.W. (2004) Short-Run and Long-Run Persistence in Mutual Funds. *Journal of Investing* 13(1): 67-71.

Jankowitsch, R. and Nettekoven, M. (2008) Trading strategies based on term structure model residuals. *European Journal of Finance* 14(4): 281-298.

Jansen, I.P. and Nikiforov, A.L. (2016) Fear and Greed: A Returns-Based Trading Strategy around Earnings Announcements. *Journal of Portfolio Management* 42(4): 88-95.

Jarrow, R.A. (2010) Understanding the risk of leveraged ETFs. *Finance Research Letters* 7(3): 135-139.

Jarrow, R., Kchia, Y., Larsson, M. and Protter, P. (2013) Discretely sampled variance and volatility swaps versus their continuous approximations. *Finance and Stochastics* 17(2): 305-324.

Jarrow, R., Lando, D. and Turnbull, S. (1997) A Markov model for the term structure of credit spreads. *Review of Financial Studies* 10(2): 481-523.

Jarrow, R.A. and Protter, P. (2012) A Dysfunctional Role of High Frequency Trading in Electronic Markets. *International Journal of Theoretical and Applied Finance* 15(3): 1250022.

Jarrow, R.A. and Turnbull, S.M. (1995) Pricing Derivatives on Financial Securities Subject to Credit Risk. *Journal of Finance* 50(1): 53-85.

Jarrow, R. and Yildirim, Y. (2003) Pricing treasury inflation protected securities and related derivatives using an HJM model. *Journal of Financial and Quantitative Analysis* 38(2): 409-430.

Jasemi, M. and Kimiagari, A.M. (2012) An investigation of model selection criteria for technical analysis of moving average. *Journal of Industrial Engineering International* 8: 5.

Jegadeesh, N. (1990) Evidence of Predictable Behavior of Security Returns. *Journal of Finance* 45(3): 881-898.

Jegadeesh, N. and Titman, S. (1993) Returns to Buying Winners and Selling Losers: Implications for Stock Market Efficiency. *Journal of Finance* 48(1): 65-91.

Jegadeesh, N. and Titman, S. (1995) Overreaction, delayed reaction, and contrarian profits. *Review of Financial Studies* 8(4): 973-993.

Jegadeesh, N. and Titman, S. (2001) Profitability of Momentum Strategies: An Evaluation of Alternative Explanations. *Journal of Finance* 56(2): 699-720.

Jensen, M.C. (1968) The Performance of Mutual Funds in the Period 1945-1964. *Journal of Finance* 23(2): 389-416.

Jensen, G.R., Johnson, R.R. and Mercer, J.M. (2000) Efficient use of commodity futures in diversified portfolios. *Journal of Futures Markets* 20(5): 489-506.

Jensen, G.R., Johnson, R.R. and Mercer, J.M. (2002) Tactical Asset Allocation and Commodity Futures. *Journal of Portfolio Management* 28(4): 100-111.

Jermann, U.J. (2016) Negative Swap Spreads and Limited Arbitrage. *Working Paper.* Available online: `https://ssrn.com/abstract=2737408`.

Jetley, G. and Ji, X. (2010) The shrinking merger arbitrage spread: Reasons and implications. *Financial Analysts Journal* 66(2): 54-68.

Jewson, S. (2004a) Weather Derivative Pricing and the Distributions of Standard Weather Indices on US Temperatures. *Working Paper.* Available online: `https://ssrn.com/abstract=535982`.

Jewson, S. (2004b) Introduction to Weather Derivative Pricing. *Working Paper.* Available online: `https://ssrn.com/abstract=557831`.

Jewson, S., Brix, A. and Ziehmann, C. (2005) *Weather Derivative Valuation: The Meteorological, Statistical, Financial and Mathematical Foundations.* Cambridge, UK: Cambridge University Press.

Jewson, S. and Caballero, R. (2003) Seasonality in the statistics of surface air temperature and the pricing of weather derivatives. *Meteorological Applications* 10(4): 367-376.

Jha, R. and Kalimipal, M. (2010) The economic significance of conditional skewness in index option markets. *Journal of Futures Markets* 30(4): 378-406.

Jiang, H., Li, D. and Wang, A. (2017) Dynamic Liquidity Management by Corporate Bond Mutual Funds. *Working Paper.* Available online: `https://ssrn.com/abstract=2776829`.

Jiang, W., Li, K. and Wang, W. (2012) Hedge Funds and Chapter 11. *Journal of Finance* 67(2): 513-560.

Jiang, Z. and Liang, J. (2017) Cryptocurrency Portfolio Management with Deep Reinforcement Learning. *Working Paper.* Available online: `https://arxiv.org/pdf/1612.01277.pdf`.

Jiang, X. and Peterburgsky, S. (2017) Investment performance of shorted leveraged ETF pairs. *Applied Economics* 49(44): 4410-4427.

Jo, H., Han, I. and Lee, H. (1997) Bankruptcy prediction using case-based reasoning, neural networks, and discriminant analysis. *Expert Systems with Applications* 13(2): 97-108.

Jobst, A. (2005) Tranche Pricing in Subordinated Loan Securitization. *Journal of Structured Finance* 11(2): 64-96.

Jobst, A. (2006a) European Securitization: A GARCH Model of Secondary Market Spreads. *Journal of Structured Finance* 12(1): 55-80.

Jobst, A. (2006b) Sovereign Securitization in Emerging Markets. *Journal of Structured Finance* 12(3): 2-13.

Jobst, A. (2006c) Correlation, Price Discovery and Co-movement of ABS and Equity. *Derivatives Use, Trading & Regulation* 12(1-2): 60-101.

Jobst, A. (2007) A Primer on Structured Finance. *Journal of Derivatives & Hedge Funds* 13(3): 199-213.

John, W. and Brigitte, U. (2009) Measuring Global Money Laundering: "The Walker Gravity Model". *Review of Law & Economics* 5(2): 821-853.

Johnson, H.F. (1979) Is It Better to Go Naked on the Street? A Primer on the Options Market. *Notre Dame Lawyer (Notre Dame Law Review)* 55(1): 7-32.

Johnson, T.C. (2002) Rational Momentum Effects. *Journal of Finance* 57(2): 585-608.

Johnson, T.C. (2008) Volume, liquidity, and liquidity risk. *Journal of Financial Economics* 87(2): 388-417.

Jones, F.J. (1991) Yield Curve Strategies. *Journal of Fixed Income* 1(2): 43-48.

Jones, C.M., Lamont, O. and Lumsdaine, R.L. (1998) Macroeconomic news and bond market volatility. *Journal of Financial Economics* 47(3): 315-337.

Jongadsayakul, W. (2016) A Box Spread Test of the SET50 Index Options Market Efficiency: Evidence from the Thailand Futures Exchange. *International Journal of Economics and Financial Issues* 6(4): 1744-1749.

Jongadsayakul, W. (2017) Arbitrage Opportunity In Thailand Futures Exchange: An Empirical Study of SET50 Index Options. In: *2017 IACB, ICE & ISEC Proceedings*, Paper No. 381. Littleton, CO: Clute Institute.

Jonsson, J. and Fridson, M. (1996) Forecasting Default Rates on High Yield Bonds. *Journal of Fixed Income* 6(1): 69-77.

Jordan, B.D. and Jordan, S. (1997) Special repo rates: An empirical analysis. *Journal of Finance* 52(5): 2051-2072.

Joseph, A. (1952) The Whittaker-Henderson Method of Graduation. *Journal of the Institute of Actuaries* 78(1): 99-114.

Joshi, N.N. and Lambert, J.H. (2011) Diversification of infrastructure projects for emergent and unknown non-systematic risks. *Journal of Risk Research* 14(6): 717-733.

Joslin, S. and Konchitchki, Y. (2018) Interest rate volatility, the yield curve, and the macroeconomy. *Journal of Financial Economics* 128(2): 344-362.

Joslin, S., Priebsch, M. and Singleton, K.J. (2014) Risk Premiums in Dynamic Term Structure Models with Unspanned Macro Risks. *Journal of Finance* 69(3): 1197-1233.

Jostarndt, P. and Sautner, Z. (2010) Out-of-Court Restructuring versus Formal Bankruptcy in a Non-Interventionist Bankruptcy Setting. *Review of Finance* 14(4): 623-668.

Jostova, G., Nikolova, S., Philipov, A. and Stahel, C.W. (2013) Momentum in Corporate Bond Returns. *Review of Financial Studies* 26(7): 1649-1693.

Joyce, M., Lildholdt, P. and Sorensen, S. (2010) Extracting Inflation Expectations and Inflation Risk Premia from the Term Structure: A Joint Model of the UK Nominal and Real Yield Curves. *Journal of Banking & Finance* 34(2): 281-294.

Judd, K.L., Kubler, F. and Schmedders, K. (2011) Bond Ladders and Optimal Portfolios. *Review of Financial Studies* 24(12): 4123-4166.

Julio, I.F., Hassan, M.K. and Ngene, G.M. (2013) Trading Strategies in Futures Markets. *Global Journal of Finance and Economics* 10(1): 1-12.

Junkus, J.C. (1991) Systematic skewness in futures contracts. *Journal of Futures Markets* 11(1): 9-24.

Jurek, J.W. (2014) Crash-neutral currency carry trades. *Journal of Financial Economics* 113(3): 325-347.

Kablan, A. (2009) Adaptive Neuro-Fuzzy Inference System for Financial Trading using Intraday Seasonality Observation Model. *International Journal of Economics and Management Engineering* 3(10): 1909-1918.

Kahn, R.N. and Lemmon, M. (2015) Smart Beta: The Owner's Manual. *Journal of Portfolio Management* 41(2): 76-83.

Kahn, R.N. and Lemmon, M. (2016) The Asset Manager's Dilemma: How Smart Beta Is Disrupting the Investment Management Industry. *Financial Analysts Journal* 72(1): 15-20.

Kahneman, D. and Tversky, A. (1979) Prospect theory: an analysis of decision under risk. *Econometrica* 47(2): 263-292.

Kakodkar, A., Galiani, S., Jónsson, J.G. and Gallo, A. (2006) *Credit Derivatives Handbook 2006 – Vol. 2: A Guide to the Exotics Credit Derivatives Market.* New York, NY: Credit Derivatives Strategy, Merrill Lynch.

Kakushadze, Z. (2015a) Phynance. *Universal Journal of Physics and Application* 9(2): 64-133. Available online: https://ssrn.com/abstract=2433826.

Kakushadze, Z. (2015b) Mean-Reversion and Optimization. *Journal of Asset Management* 16(1): 14-40. Available online: https://ssrn.com/abstract=2478345.

Kakushadze, Z. (2015c) 4-Factor Model for Overnight Returns. *Wilmott Magazine* 2015(79): 56-62. Available online: https://ssrn.com/abstract=2511874.

Kakushadze, Z. (2015d) On Origins of Alpha. *Hedge Fund Journal* 108: 47-50. Available online: https://ssrn.com/abstract=2575007.

Kakushadze, Z. (2015e) Heterotic Risk Models. *Wilmott Magazine* 2015(80): 40-55. Available online: https://ssrn.com/abstract=2600798.

Kakushadze, Z. (2016) 101 Formulaic Alphas. *Wilmott Magazine* 2016(84): 72-80. Available online: https://ssrn.com/abstract=2701346.

Kakushadze, Z. and Tulchinsky, I. (2016) Performance v. Turnover: A Story by 4,000 Alphas. *Journal of Investment Strategies* 5(2): 75-89. Available online: http://ssrn.com/abstract=2657603.

Kakushadze, Z. and Yu, W. (2016a) Multifactor Risk Models and Heterotic CAPM. *Journal of Investment Strategies* 5(4): 1-49. Available online: https://ssrn.com/abstract=2722093.

Kakushadze, Z. and Yu, W. (2016b) Statistical Industry Classification. *Journal of Risk & Control* 3(1): 17-65. Available online: https://ssrn.com/abstract=2802753.

Kakushadze, Z. and Yu, W. (2017a) Statistical Risk Models. *Journal of Investment Strategies* 6(2): 1-40. Available online: https://ssrn.com/abstract=2732453.

Kakushadze, Z. and Yu, W. (2017b) How to Combine a Billion Alphas. *Journal of Asset Management* 18(1): 64-80. Available online: https://ssrn.com/abstract=2739219.

Kakushadze, Z. and Yu, W. (2017c) *K-Means and Cluster Models for Cancer Signatures. *Biomolecular Detection and Quantification* 13: 7-31. Available online: https://ssrn.com/abstract=2908286.

Kakushadze, Z. and Yu, W. (2018a) Decoding Stock Market with Quant Alphas. *Journal of Asset Management* 19(1): 38-48. Available online: https://ssrn.com/abstract=2965224.

Kakushadze, Z. and Yu, W. (2018b) Notes on Fano Ratio and Portfolio Optimization. *Journal of Risk & Control* 5(1): 1-33. Available online: https://ssrn.com/abstract=3050140.

Kalev, P.S. and Inder, B.A. (2006) The information content of the term structure of interest rates. *Applied Economics* 38(1): 33-45.

Kallberg, J.G., Liu, C.L. and Trzcinka, C. (2000) The Value Added from Investment Managers: An Examination of Funds of REITs. *Journal of Financial and Quantitative Analysis* 35(3): 387-408.

Kalman, P.E. (1960) A New Approach to Linear Filtering and Prediction Problems. *Journal of Basic Engineering* 82(1): 35-45.

Kambhu, J. (2006) Trading Risk, Market Liquidity, and Convergence Trading in the Interest Rate Swap Spread. *Federal Reserve Bank of New York, Economic Policy Review* 12(1): 1-13.

Kaminski, V. (2004) *Managing Energy Price Risk: The New Challenges and Solutions.* London, UK: Risk Books.

Kandel, S., Ofer, A.R. and Sarig, O. (1996) Real Interest Rates and Inflation: An Ex-Ante Empirical Analysis. *Journal of Finance* 51(1): 205-225.

Kandel, S. and Stambaugh, R.F. (1987) Long-horizon Returns and Short-horizon Models. *CRSP Working Paper No. 222.* Chicago, IL: University of Chicago.

Kang, H.B. and Gardner, J. (1989) Selling Price and Marketing Time in the Residential Real Estate Market. *Journal of Real Estate Research* 4(1): 21-35.

Kang, J.K. and Lee, Y.W. (1996) The pricing of convertible debt offerings. *Journal of Financial Economics* 41(2): 231-248.

Kang, J., Liu, M.H. and Ni, S.X. (2002) Contrarian and momentum strategies in the China stock market: 1993-2000. *Pacific-Basin Finance Journal* 10(3): 243-265.

Kapadia, N. and Szado, E. (2007) The Risk Return Characteristics of the Buy-Write Strategy on the Russell 2000 Index. *Journal of Alternative Investments* 9(4): 39-56.

Kaplan, P. and Lummer, S.L. (1998) Update: GSCI Collateralized Futures as a Hedging Diversification Tool for Institutional Portfolios. *Journal of Investing* 7(4): 11-18.

Kara, Y., Boyacioglu, M.A. and Baykan, O.K. (2011) Predicting direction of stock price index movement using artificial neural networks and support vector machines: The sample of the Istanbul Stock Exchange. *Expert Systems with Applications* 38(5): 5311-5319.

Karlik, B. and Vehbi, A. (2011) Performance Analysis of Various Activation Functions in Generalized MLP Architectures of Neural Networks. *International Journal of Artificial Intelligence and Expert Systems* 1(4): 111-122.

Karolyi, G.A. and Kho, B.C. (2004) Momentum strategies: Some bootstrap tests. *Journal of Empirical Finance* 11(4): 509-536.

Karolyi, G.A. and Sanders, A.B. (1998) The Variation of Economic Risk Premiums in Real Estate Returns. *Journal of Real Estate Finance and Economics* 17(3): 245-262.

Karolyi, G.A. and Shannon, J. (1999) Where's the Risk in Risk Arbitrage? *Canadian Investment Review* 12(2): 12-18.

Kau, J.B., Keenan, D.C., Muller, W.J., III and Epperson, J.F. (1995) The valuation at origination of fixed-rate mortgages with default and prepayment. *Journal of Real Estate Finance and Economics* 11(1): 5-36.

Kawaller, I.G., Koch, P.D. and Ludan, L. (2002) Calendar spreads, outright futures positions and risk. *Journal of Alternative Investments* 5(3): 59-74.

Kazemi, H. and Li, Y. (2009) Market timing of CTAs: An examination of systematic CTAs vs. discretionary CTAs. *Journal of Futures Markets* 29(11): 1067-1099.

Keane, F. (1996) Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York, Current Issues in Economics and Finance* 2(10): 1-6.

Kelly, J.L. (1956) A New Interpretation of Information Rate. *Bell System Technical Journal* 35(4): 917-926.

Kemp, K. (2007) *Flipping confidential: The secrets of renovating property for profit in any market.* Hoboken, NJ: John Wiley & Sons, Inc.

Kenett, D.Y., Ben-Jacob, E., Stanley, H.E. and gur-Gershgoren, G. (2013) How High Frequency Trading Affects a Market Index. *Scientific Reports* 3: 2110.

Kenyon, C. (2008) Inflation is normal. *Risk*, July 2008, pp. 76-82.

Khan, S.A. (2002) Merger Arbitrage: A Long-Term Investment Strategy. *Journal of Wealth Management* 4(4): 76-81.

Khandani, A. and Lo, A.W. (2011) What Happened to the Quants in August 2007? Evidence from Factors and Transactions Data. *Journal of Financial Markets* 14(1): 1-46.

Khang, C.H. (1983) A dynamic global portfolio immunization strategy in the world of multiple interest rate changes: A dynamic immunization and minimax theorem. *Journal of Financial and Quantitative Analysis* 18(3): 355-363.

Khuzwayo, B. and Maré, E. (2014) Aspects of volatility targeting for South African equity investors. *South African Journal of Economic and Management Sciences* 17(5): 691-699.

Kidd, D. (2014) Global Tactical Asset Allocation: One Strategy Fits All? In: *Investment Risk and Performance.* Charlottesville, VA: CFA Institute.

Kilgallen, T. (2012) Testing the Simple Moving Average across Commodities, Global Stock Indices, and Currencies. *Journal of Wealth Management* 15(1): 82-100.

Kim, I.J. (1990) The analytic valuation of American options. *Review of Financial Studies* 3(4): 547-572.

Kim, K. (2011) Performance Analysis of Pairs Trading Strategy Utilizing High Frequency Data with an Application to KOSPI 100 Equities. *Working Paper.* Available online: https://ssrn.com/abstract=1913707.

Kim, K.J. (2003) Financial time series forecasting using support vector machines. *Neurocomputing* 55(1-2): 307-319.

Kim, K.J. (2006) Artificial neural networks with evolutionary instance selection for financial forecasting. *Expert Systems with Applications* 30(3): 519-526.

Kim, Y. and Enke, D. (2016) Using neural networks to forecast volatility for an asset allocation strategy based on the target volatility. *Procedia Computer Science* 95: 281-286.

Kim, K. and Han, I. (2000) Genetic algorithms approach to feature discretization in artificial neural networks for the prediction of stock price index. *Expert Systems with Applications* 19(2): 125-132.

Kim, M.-K. and Leuthold, R.M. (1997) The Distributional Behavior of Futures Price Spread Changes: Parametric and Nonparametric Tests for Gold, T-Bonds, Corn, and Live Cattle. *Working Paper*. Available online: `https://ageconsearch.umn.edu/bitstream/14767/1/aceo9703.pdf`.

Kim, G.H., Li, H. and Zhang, W. (2016) CDS-Bond Basis and Bond Return Predictability. *Journal of Empirical Finance* 38: 307-337.

Kim, G.H., Li, H. and Zhang, W. (2017) The CDS-Bond Basis Arbitrage and the Cross Section of Corporate Bond Returns. *Journal of Futures Markets* 37(8): 836-861.

Kim, Y.B., Kim, J.G., Kim, W., Im, J.H., Kim, T.H., Kang, S.J. and Kim, C.H. (2016) Predicting Fluctuations in Cryptocurrency Transactions Based on User Comments and Replies. *PLoS ONE* 11(8): e0161197.

King, R. (1986) Convertible Bond Valuation: An Empirical Test. *Journal of Financial Research* 9(1): 53-69.

King, T.H.D. and Mauer, D.C. (2014) Determinants of corporate call policy for convertible bonds. *Journal of Corporate Finance* 24: 112-134.

Kingma, D.P. and Ba, J. (2014) Adam: A Method for Stochastic Optimization. *Working Paper*. Available online: `https://arxiv.org/pdf/1412.6980`.

Kirby, C. and Ostdiek, B. (2012) It's All in the Timing: Simple Active Portfolio Strategies that Outperform Naïve Diversification. *Journal of Financial and Quantitative Analysis* 47(2): 437-467.

Kirilenko, A., Kyle, A., Samadi, M. and Tuzun, T. (2017) The Flash Crash: High-Frequency Trading in an Electronic Market. *Journal of Finance* 72(3): 967-998.

Kishore, V. (2012) Optimizing Pairs Trading of US Equities in a High Frequency Setting. *Working Paper.* Available online: https://repository.upenn.edu/cgi/viewcontent.cgi?article=1095&context=wharton_research_scholars.

Kitsul, Y. and Wright, J.H. (2013) The Economics of Options-Implied Inflation Probability Density Functions. *Journal of Financial Economics* 110(3): 696-711.

Klingler, S. and Sundaresan, S.M. (2016) An Explanation of Negative Swap Spreads: Demand for Duration from Underfunded Pension Plans. *Working Paper.* Available online: https://ssrn.com/abstract=2814975.

Knight, J.R. (2002) Listing Price, Time on Market, and Ultimate Selling Price: Causes and Effects of Listing Price Changes. *Real Estate Economics* 30(2): 213-237.

Kobor, A., Shi, L. and Zelenko, I. (2005) What Determines U.S. Swap Spreads? *World Bank Working Paper No. 62.* Washington, DC: World Bank.

Kocherlakota, R., Rosenbloom, E. and Shiu, E. (1988) Algorithms for cash-flow matching. *Transactions of Society of Actuaries* 40: 477-484.

Kocherlakota, R., Rosenbloom, E. and Shiu, E. (1990) Cash-flow matching and linear programming duality. *Transactions of Society of Actuaries* 42: 281-293.

Kochin, L. and Parks, R. (1988) Was the tax-exempt bond market inefficient or were future expected tax rates negative? *Journal of Finance* 43(4): 913-931.

Koijen, R.S.J., Moskowitz, T.J., Pedersen, L.H. and Vrugt, E.B. (2018) Carry. *Journal of Financial Economics* 127(2): 197-225.

Kolb, R.W. and Chiang, R. (1981) Improving Hedging Performance Using Interest Rate Futures. *Financial Management* 10(3): 72-79.

Kolb, R.W. and Chiang, R. (1982) Duration, Immunization, and Hedging with Interest Rate Futures. *Journal of Financial Research* 5(2): 161-170.

Konstantinidi, E. and Skiadopoulos, G. (2016) How does the market variance risk premium vary over time? Evidence from S&P 500 variance swap investment returns. *Journal of Banking & Finance* 62: 62-75.

Koopman, S.J., Lucas, A. and Schwaab, B. (2012) Dynamic factor models with macro, frailty, and industry effects for U.S. default counts: The credit crisis of 2008. *Econometric Reviews* 30(4): 521-532.

Korajczyk, R.A. and Murphy, D. (2017) High Frequency Market Making to Large Institutional Trades. *Working Paper.* Available online: https://ssrn.com/abstract=2567016.

Korajczyk, R.A. and Sadka, R. (2004) Are momentum profits robust to trading costs? *Journal of Finance* 59(3): 1039-1082.

Kordonis, J., Symeonidis, A. and Arampatzis, A. (2016) Stock Price Forecasting via Sentiment Analysis on Twitter. In: *Proceedings of the 20th Pan-Hellenic Conference on Informatics (PCI'16).* New York, NY: ACM, Article No. 36.

Kordos, M. and Cwiok, A. (2011) A new approach to neural network based stock trading strategy. In: Yin, H., Wang, W. and Rayward-Smith, V. (eds.) *Intelligent Data Engineering and Automated Learning-IDEAL.* Berlin, Germany: Springer, pp. 429-436.

Korkeamaki, T. and Michael, T.B. (2013) Where are they now? An analysis of the life cycle of convertible bonds. *Financial Review* 48(3): 489-509.

Korol, T. (2013) Early warning models against bankruptcy risk for Central European and Latin American enterprises. *Economic Modelling* 31: 22-30.

Kozhan, R., Neuberger, A. and Schneider, P. (2013) The Skew Risk Premium in the Equity Index Market. *Review of Financial Studies* 26(9): 2174-2203.

Kozhan, R. and Tham, W.W. (2012) Execution Risk in High-Frequency Arbitrage. *Management Science* 58(11): 2131-2149.

Kozhemiakin, A.V. (2007) The Risk Premium of Corporate Bonds. *Journal of Portfolio Management* 33(2): 101-109.

Kozicki, S. and Tinsley, P.A. (2012) Effective Use of Survey Information in Estimating the Evolution of Expected Inflation. *Journal of Money, Credit and Banking* 44(1): 145-169.

Kozlov, M. and Petajisto, A. (2013) Global Return Premiums on Earnings Quality, Value, and Size. *Working Paper.* Available online: https://ssrn.com/abstract=2179247.

Kraenzlin, S. (2007) The characteristics and development of the Swiss franc repurchase agreement market. *Financial Markets and Portfolio Management* 21(2): 241-261.

Krainer, J. (2001) A Theory of Liquidity in Residential Real Estate Markets. *Journal of Urban Economics* 49(1): 32-53.

Krause, T., Ehsani, S. and Lien, D. (2014) Exchange-traded funds, liquidity and volatility. *Applied Financial Economics* 24(24): 1617-1630.

Krauss, C. (2017) Statistical arbitrage pairs trading strategies: Review and outlook. *Journal of Economic Surveys* 31(2): 513-545.

Krauss, C. and Stübinger, J. (2017) Non-linear dependence modelling with bivariate copulas: Statistical arbitrage pairs trading on the S&P 100. *Applied Economics* 23(1): 1-18.

Krishnamurthy, A. (2002) The Bond/Old-Bond Spread. *Journal of Financial Economics* 66(2): 463-506.

Kristoufek, L. (2015) What Are the Main Drivers of the Bitcoin Price? Evidence from Wavelet Coherence Analysis. *PLoS ONE* 10(4): e0123923.

Kroner, K.F. and Sultan, J. (1993) Time-Varying Distributions and Dynamic Hedging with Foreign Currency Futures. *Journal of Financial and Quantitative Analysis* 28(4): 535-551.

Kruttli, M., Monin, P. and Watugala, S.W. (2018) Investor Concentration, Flows, and Cash Holdings: Evidence from Hedge Funds. *Working Paper.* Available online: `https://ssrn.com/abstract=3031663`.

Kryzanowski, L., Galler, M. and Wright, D. (1993) Using Artificial Neural Networks to Pick Stocks. *Financial Analysts Journal* 49(4): 21-27.

Kuberek, R.C. and Pefley, N.G. (1983) Hedging Corporate Debt with U.S. Treasury Bond Futures. *Journal of Futures Markets* 3(4): 345-353.

Kudryavtsev, A. (2012) Overnight stock price reversals. *Journal of Advanced Studies in Finance* 3(2): 162-170.

Kuhle, J. and Alvayay, J. (2000) The Efficiency of Equity REIT Prices. *Journal of Real Estate Portfolio Management* 6(4): 349-354.

Kumar, A. (2009) Who Gambles in the Stock Market? *Journal of Finance* 64(4): 1889-1933.

Kumar, V.A. (2012) Money Laundering: Concept, Significance and its Impact. *European Journal of Business and Management* 4(2): 113-119.

Kumar, M. and Thenmozhi, M. (2001) Forecasting Stock Index Movement: A Comparison of Support Vector Machines and Random Forest. *Working Paper.* Available online: `https://ssrn.com/abstract=876544`.

Kwok, Y.K. (2014) Game option models of convertible bonds: Determinants of call policies. *Journal of Financial Engineering* 1(4): 1450029.

Lafuente, J.A. (2013) Optimal cross-hedging under futures mispricing: A note. *Journal of Derivatives & Hedge Funds* 19(3): 181-188.

Lahmiri, S. (2014) Wavelet low- and high-frequency components as features for predicting stock prices with backpropagation neural networks. *Journal of King Saud University – Computer and Information Sciences* 26(2): 218-227.

Lai, H.-C., Tseng, T.-C. and Huang, S.-C. (2016) Combining value averaging and Bollinger Band for an ETF trading strategy. *Applied Economics* 48(37): 3550-3557.

Laitinen, E.K. and Laitinen, T. (2000) Bankruptcy prediction application of the Taylor's expansion in logistic regression. *International Review of Financial Analysis* 9(4): 327-349.

Lakonishok, J., Lee, I., Pearson, N.D. and Poteshman, A.M. (2007) Option market activity. *Review of Financial Studies* 20(3): 813-857.

Lakonishok, J., Shleifer, A. and Vishny, R.W. (1994) Contrarian investment, extrapolation, and risk. *Journal of Finance* 49(5): 1541-1578.

Lakonishok, J. and Vermaelen, T. (1986) Tax-Induced Trading Around the Ex-Day. *Journal of Financial Economics* 16(3): 287-319.

Lambert, M., Papageorgiou, N. and Platania, F. (2006) Market Efficiency and Hedge Fund Trading Strategies. *Working Paper.* Available online: `https://www.edhec.edu/sites/www.edhec-portail.pprod.net/files/edhec_working_paper_market_efficiency_and_hedge_fund_trading_strategies_f.compressed.pdf`.

Lamoureux, C.G. and Lastrapes, W. (1993) Forecasting stock return variance: towards understanding stochastic implied volatility. *Review of Financial Studies* 6(2): 293-326.

Lamoureux, C. and Wansley, J. (1987) Market Effects of Changes in the S&P 500 Index. *Financial Review* 22(1): 53-69.

Landes, W.J., Stoffels, J.D. and Seifert, J.A. (1985) An Empirical Test of a Duration-Based Hedge: The Case of Corporate Bonds. *Journal of Futures Markets* 5(2): 173-182.

Lang, L.H.P., Litzenberger, R.H. and Liu, A.L. (1998) Determinants of Interest Rate Swap Spreads. *Journal of Banking & Finance* 22(12): 1507-1532.

Langetieg, T.C., Leibowitz, L. and Kogelman, S. (1990) Duration Targeting and the Management of Multiperiod Returns. *Financial Analysts Journal* 46(5): 35-45.

Larker, D. and Lys, T. (1987) An empirical analysis of the incentives to engage in costly information acquisition: The case of risk arbitrage. *Journal of Financial Economics* 18(1): 111-126.

Larkin, D.E., Babin, M.L. and Rose, C.A. (2004) Structuring European real estate private equity funds. *Briefings in Real Estate Finance* 3(3): 229-235.

Larsen, G. and Resnick, B. (1998) Empirical Insights on Indexing. *Journal of Portfolio Management* 25(1): 51-60.

Larsson, P. and Flohr, L. (2011) Optimal proxy-hedging of options on illiquid baskets. *Working Paper.* Available online: `https://www.math.kth.se/matstat/seminarier/reports/M-exjobb11/110131a.pdf`.

Lasfer, M.A. (1995) Ex-Day Behavior: Tax or Short-Term Trading Effects. *Journal of Finance* 50(3): 875-897.

Laurent, J.-P. and Gregory, J. (2005) Basket Default Swaps, CDOs and Factor Copulas. *Journal of Risk* 7(4): 8-23.

Laurent, J.-P., Cousin, A. and Fermanian, J.D. (2011) Hedging default risks of CDOs in Markovian contagion models. *Quantitative Finance* 11(12): 1773-1791.

Laureti, P., Medo, M. and Zhang, Y.-C. (2010) Analysis of Kelly-optimal portfolios. *Quantitative Finance* 10(7): 689-697.

Lautier, D. and Galli, A. (2004) Simple and extended Kalman filters: an application to term structures of commodity prices. *Applied Financial Economics* 14(13): 963-973.

Lazo, J.K., Lawson, M., Larsen, P.H. and Waldman, D.M. (2011) U.S. Economic Sensitivity to Weather Variability. *Bulletin of the American Meteorological Society* 92(6): 709-720.

Lebeck, W.W. (1978) Futures trading and hedging. *Food Policy* 3(1): 29-35.

Lee, S. (2010) The Changing Benefit of REITs to the Multi-Asset Portfolio. *Journal of Real Estate Portfolio Management* 16(3): 201-215.

Lee, D.K.C., Guo, L. and Wang, Y. (2018) Cryptocurrency: A New Investment Opportunity? *Journal of Alternative Investments* 20(3): 16-40.

Lee, H., Liao, T. and Tung, P. (2017) Investors' Heterogeneity in Beliefs, the VIX Futures Basis, and S&P 500 Index Futures Returns. *Journal of Futures Markets* 37(9): 939-960.

Lee, S.B. and Oh, S.H. (1993) Managing non-parallel shift risk of yield curve with interest rate futures. *Journal of Futures Markets* 13(5): 515-526.

Lee, Y. and Oren, S. (2009) An equilibrium pricing model for weather derivatives in a multi-commodity setting. *Energy Economics* 31(5): 702-713.

Lee, S. and Stevenson, S. (2005) The Case for REITs in the Mixed-Asset Portfolio in the Short and Long Run. *Journal of Real Estate Portfolio Management* 11(1): 55-80.

Leggio, K. and Lien, D. (2002) Hedging gas bills with weather derivatives. *Journal of Economics and Finance* 26(1): 88-100.

Lehecka, G.V. (2013) Hedging and Speculative Pressures: An Investigation of the Relationships among Trading Positions and Prices in Commodity Futures Markets. In: *Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management.* Available online: `http://www.farmdoc.illinois.edu/nccc134/conf_2013/pdf/Lehecka_NCCC-134_2013.pdf`.

Lehmann, B.N. (1990) Fads, Martingales, and Market Efficiency. *Quarterly Journal of Economics* 105(1): 1-28.

Leibowitz, M.L. and Bova, A. (2013) Duration Targeting and Index Convergence. *Morgan Stanley Investment Management Journal* 3(1): 73-80.

Leibowitz, M.L., Bova, A. and Kogelman, S. (2014) Long-Term Bond Returns under Duration Targeting. *Financial Analysts Journal* 70(1): 31-51.

Leibowitz, M.L., Bova, A. and Kogelman, S. (2015) Bond Ladders and Rolling Yield Convergence. *Financial Analysts Journal* 71(2): 32-46.

Leigland, J. (2018) Changing Perceptions of PPP Risk and Return: The Case of Brownfield Concessions. *Journal of Structured Finance* 23(4): 47-56.

Leland, H. and Connor, G. (1995) Optimal Cash Management for Investment Funds. *Research Program in Finance Working Papers*, No. RPF-244. Berkeley, CA: University of California at Berkeley.

Leland, E.C. and Panos, N. (1997) The Puttable Bond Market: Structure, Historical Experience, and Strategies. *Journal of Fixed Income* 7(3): 47-60.

Le Moigne, C. and Viveiros, É. (2008) Private Real Estate as an Inflation Hedge: An Updated Look with a Global Perspective. *Journal of Real Estate Portfolio Management* 14(4): 263-286.

Leontsinis, S. and Alexander, C. (2016) Arithmetic variance swaps. *Quantitative Finance* 17(4): 551-569.

Lessambo, F.I. (2016) *International Aspects of the US Taxation System.* New York, NY: Palgrave Macmillan.

Leung, T., Li, J., Li, X. and Wang, Z. (2016) Speculative Futures Trading under Mean Reversion. *Asia-Pacific Financial Markets* 23(4): 281-304.

Leung, C.K.Y. and Tse, C.-Y. (2013) Flippers in housing market search. *Working Paper.* Available online: https://hub.hku.hk/bitstream/10722/190689/1/Content.pdf.

Levi, M. and Reuter, P. (2006) Money Laundering. *Crime and Justice* 34(1): 289-375.

Levin, A. and Davidson, A. (2005) Prepayment Risk-and Option-Adjusted Valuation of MBS. *Journal of Portfolio Management* 31(4): 73-85.

Levine, A. and Pedersen, L.H. (2016) Which Trend Is Your Friend? *Financial Analysts Journal* 72(3): 51-66.

Levis, M. and Liodakis, M. (1999) The Profitability of Style Rotation Strategies in the United Kingdom. *Journal of Portfolio Management* 26(1): 73-86.

Levitt, S.D. and Syverson, C. (2008) Market Distortions When Agents Are Better Informed: The Value of Information in Real Estate Transactions. *Review of Economics and Statistics* 90(4): 599-611.

Levy, P.S. (1991) Approaches to Investing in Distressed Securities: Active Approaches. In: Bowman, T.A. (ed.) *Analyzing Investment Opportunities in Distressed and Bankrupt Companies.* (AIMR Conference Proceedings, Vol. 1991, Iss. 1.) Chicago, IL: AIMR, pp. 44-46.

Levy, A. and Lieberman, O. (2013) Overreaction of country ETFs to US market returns: Intraday vs. daily horizons and the role of synchronized trading. *Journal of Banking & Finance* 37(5): 1412-1421.

Lewis, K. (1995) Puzzles in International Financial Markets. In: Grossman G.M. and Rogoff, K. (eds.) *Handbook of International Economics*, Vol. 3. Amsterdam, The Netherlands: North-Holland, Chapter 37.

Lewis, M. (2014) *Flash Boys: A Wall Street Revolt.* New York, NY: W.W. Norton & Company, Inc.

Lewis, C.M., Rogalski, R.J. and Seward, J.K. (1999) Is convertible debt a substitute for straight debt or for common equity? *Financial Management* 28(3): 5-27.

Lewis, C.M. and Verwijmeren, P. (2011) Convertible security design and contract innovation. *Journal of Corporate Finance* 17(4): 809-831.

Lhabitant, F.-S. (2002) *Hedge Funds: Myths and Limits.* Chichester, UK: John Wiley & Sons, Ltd.

L'Hoir, M. and Boulhabel, M. (2010) A Bond-Picking Model for Corporate Bond Allocation. *Journal of Portfolio Management* 36(3): 131-139.

Li, D.X. (2000) On default correlation: a copula function approach. *Journal of Fixed Income* 9(4): 43-54.

Li, T.R., Chamrajnagar, A.S., Fong, X.R., Rizik, N.R. and Fu, F. (2018) Sentiment-Based Prediction of Alternative Cryptocurrency Price Fluctuations Using Gradient Boosting Tree Model. *Working Paper.* Available online: `https://arxiv.org/pdf/1805.00558.pdf`.

Li, X., Deng, X., Zhu, S., Wang, F. and Xie, H. (2014) An intelligent market making strategy in algorithmic trading. *Frontiers of Computer Science* 8(4): 596-608.

Li, B., Hoi, S.C.H., Sahoo, D. and Liu, Z.-Y. (2015) Moving average reversion strategy for on-line portfolio selection. *Artificial Intelligence* 222: 104-123.

Li, L. and Kleindorfer, P.R. (2009) On hedging spark spread options in electricity markets. *Risk and Decision Analysis* 1(4): 211-220.

Li, X., Sullivan, R.N. and Garcia-Feijóo, L. (2014) The Limits to Arbitrage and the Low-Volatility Anomaly. *Financial Analysts Journal* 70(1): 52-63.

Li, X., Sullivan, R.N. and Garcia-Feijóo, L. (2016) The Low-Volatility Anomaly: Market Evidence on Systematic Risk vs. Mispricing. *Financial Analysts Journal* 72(1): 36-47.

Li, Y. and Wang, K. (1995) The Predictability of REIT Returns and Market Segmentation. *Journal of Real Estate Research* 10(5): 471-482.

Li, P. and Yang, J. (2017) Pricing Collar Options with Stochastic Volatility. *Discrete Dynamics in Nature and Society* 2017: 9673630.

Li, B., Zhao, P., Hoi, S.C.H. and Gopalkrishnan, V. (2012) PAMR: Passive aggressive mean reversion strategy for portfolio selection. *Machine Learning* 87(2): 221-258.

Liao, G.Y. (2016) Credit migration and covered interest rate parity. *Working Paper.* Available online: `http://scholar.harvard.edu/files/gliao/files/creditcip.pdf`.

Lien, D. (1992) Optimal Hedging and Spreading in Cointegrated Markets. *Economics Letters* 40(1): 91-95.

Lien, D. (2004) Cointegration and the Optimal Hedge Ratio: The General Case. *Quarterly Review of Economics and Finance* 44(5): 654-658.

Lien, D. (2010) The effects of skewness on optimal production and hedging decisions: An application of the skew-normal distribution. *Journal of Futures Markets* 30(3): 278-289.

Lien, D. and Luo, X. (1993) Estimating Multiperiod Hedge Ratios in Cointegrated Markets. *Journal of Futures Markets* 13(8): 909-920.

Lien, D. and Tse, Y.K. (2000) Hedging downside risk with futures contracts. *Applied Financial Economics* 10(2): 163-170.

Lien, D. and Wang, Y. (2015) Effects of skewness and kurtosis on production and hedging decisions: A skewed t distribution approach. *European Journal of Finance* 21(13-14): 1132-1143.

Liew, J.K.-S. and Budavári, T. (2016) Do Tweet Sentiments Still Predict the Stock Market? *Working Paper.* Available online: `https://ssrn.com/abstract=2820269`.

Liew, J.K.-S., Li, R.Z. and Budavári, T. (2018) Crypto-Currency Investing Examined. *Working Paper.* Available online: `https://ssrn.com/abstract=3157926`.

Liew, J.K.-S. and Mayster, B. (2018) Forecasting ETFs with Machine Learning Algorithms. *Journal of Alternative Investments* 20(3): 58-78.

Liew, J. and Roberts, R. (2013) U.S. Equity Mean-Reversion Examined. *Risks* 1(3): 162-175.

Liew, J. and Vassalou, M. (2000) Can Book-to-Market, Size and Momentum be Risk Factors that Predict Economic Growth? *Journal of Financial Economics* 57(2): 221-245.

Liew, R. and Wu, Y. (2013) Pairs trading: A copula approach. *Journal of Derivatives & Hedge Funds* 19(1): 12-30.

Lin, L., Lan, L.-H. and Chuang, S.-s. (2013) An Option-Based Approach to Risk Arbitrage in Emerging Markets: Evidence from Taiwan Takeover Attempts. *Journal of Forecasting* 32(6): 512-521.

Lin, Y.-X., McCrae, M. and Gulati, C. (2006) Loss protection in pairs trading through minimum profit bounds: A cointegration approach. *Journal of Applied Mathematics and Decision Sciences* 2006(4): 1-14.

Lin, S.-Y. and Shyy, G. (2008) Credit Spreads, Default Correlations and CDO Tranching: New Evidence from CDS Quotes. *Working Paper*. Available online: `https://ssrn.com/abstract=496225`.

Lin, C.Y. and Yung, K. (2004) Real Estate Mutual Funds: Performance and Persistence. *Journal of Real Estate Research* 26(1): 69-93.

Lindahl, M. (1992) Minimum variance hedge ratios for stock index futures: duration and expiration effects. *Journal of Futures Markets* 12(1): 33-53.

Lioui, A. and Poncet, P. (2005) General equilibrium pricing of CPI derivatives. *Journal of Banking & Finance* 29(5): 1265-1294.

Litterman, R.B. and Scheinkman, J. (1991) Common Factors Affecting Bond Returns. *Journal of Fixed Income* 1(1): 54-61.

Litzenberger, R.H. and Rabinowitz, N. (1995) Backwardation in oil futures markets: Theory and empirical evidence. *Journal of Finance* 50(3): 1517-1545.

Liu, B., Chang, L.B. and Geman, H. (2017) Intraday pairs trading strategies on high frequency data: The case of oil companies. *Quantitative Finance* 17(1): 87-100.

Liu, B. and Dash, S. (2012) Volatility ETFs and ETNs. *Journal of Trading* 7(1): 43-48.

Liu, J., Longstaff, F.A. and Mandell, R.E. (2006) The Market Price of Risk in Interest Rate Swaps: The Roles of Default and Liquidity Risks. *Journal of Business* 79(5): 2337-2360.

Liu, C.H. and Mei, J. (1992) The Predictability of Returns on Equity REITs and their Co-Movement with Other Assets. *Journal of Real Estate Finance and Economics* 5(4): 401-418.

Liu, F., Pantelous, A.A. and von Mettenheim, H.-J. (2018) Forecasting and trading high frequency volatility on large indices. *Quantitative Finance* 18(5): 737-748.

Liu, P. and Tang, K. (2010) No-arbitrage conditions for storable commodities and the models of futures term structures. *Journal of Banking & Finance* 34(7): 1675-1687.

Liu, P. and Tang, K. (2011) The stochastic behavior of commodity prices with heteroscedasticity in the convenience yield. *Journal of Empirical Finance* 18(2): 211-224.

Liu, Z.F. and van der Heijden, T. (2016) Model-Free Risk-Neutral Moments and Proxies. *Working Paper.* Available online: https://ssrn.com/abstract=2641559.

Liu, J.-G. and Xu, E. (1998) Pricing of mortgage-backed securities with option-adjusted spread. *Managerial Finance* 24(9-10): 94-109.

Liu, L.X. and Zhang, L. (2008) Momentum Profits, Factor Pricing, and Macroeconomic Risk. *Review of Financial Studies* 21(6): 2417-2448.

Liverance, E. (2010) Variance Swap. In: Cont, R. (ed.) *Encyclopedia of Quantitative Finance.* Hoboken, NJ: John Wiley & Sons, Inc.

Livnat, J. and Mendenhall, R.R. (2006) Comparing the post-earnings announcement drift for surprises calculated from analyst and time series forecasts. *Journal of Accounting Research* 44(1): 177-205.

Lo, A. (2008) Where Do Alphas Come From?: A New Measure of the Value of Active Investment Management. *Journal of Investment Management* 6(2): 1-29.

Lo, A. (2016) What Is an Index? *Journal of Portfolio Management* 42(2): 21-36.

Lo, A.W. and MacKinlay, A.C. (1990) When Are Contrarian Profits Due to Stock Market Overreaction? *Review of Financial Studies* 3(3): 175-205.

Lo, A., Mamaysky, H. and Wang, J. (2000) Foundations of Technical Analysis: Computational Algorithms, Statistical Inference, and Empirical Implementation. *Journal of Finance* 55(4): 1705-1765.

Lo, A.W., Orr, A. and Zhang, R. (2017) The Growth of Relative Wealth and the Kelly Criterion. *Working Paper.* Available online: https://ssrn.com/abstract=2900509.

Loh, R.K. and Warachka, M. (2012) Streaks in earnings surprises and the cross-section of stock returns. *Management Science* 58(7): 1305-1321.

Loncarski, I., ter Horst, J.R. and Veld, C.H. (2006) The Convertible Arbitrage Strategy Analyzed. *Working Paper.* Available online: https://pure.uvt.nl/ws/files/779871/98.pdf.

Loncarski, I., ter Horst, J. and Veld, C. (2009) The Rise and Demise of the Convertible Arbitrage Strategy. *Financial Analysts Journal* 65(5): 35-50.

Longstaff, F. (2005) Borrower Credit and the Valuation of Mortgage-Backed Securities. *Real Estate Economics* 33(4): 619-661.

Longstaff, F.A. (2011) Municipal Debt and Marginal Tax Rates: Is There a Tax Premium in Asset Prices? *Journal of Finance* 66(3): 721-751.

Low, A., Muthuswamy, J., Sakar, S. and Terry, E. (2002) Multiperiod hedging with futures contracts. *Journal of Futures Markets* 22(12): 1179-1203.

Lozovaia, T. and Hizhniakova, H. (2005) How to Extend Modern Portfolio Theory to Make Money from Trading Equity Options. *Working Paper.* Available online:
`http://www.ivolatility.com/doc/Dispersion_Article.pdf`.

Lu, C.J., Lee, T.S. and Chiu, C. (2009) Financial time series forecasting using independent component analysis and support vector regression. *Decision Support Systems* 47(2): 115-125.

Lu, L., Wang, J. and Zhang, G. (2012) Long term performance of leveraged ETFs. *Financial Services Review* 21(1): 63-80.

Lucas, D.J., Goodman, L.S. and Fabozzi, F.J. (eds.) (2006) *Collateralized Debt Obligations: Structures and Analysis.* Hoboken, NJ: John Wiley & Sons, Inc.

Lucca, D.O. and Moench, E. (2012) The Pre-FOMC Announcement Drift. *Journal of Finance* 70(1): 329-371.

Lummer, S.L. and Siegel, L.B. (1993) GSCI Collateralized Futures: A Hedging and Diversification Tool for Institutional Portfolio. *Journal of Investing* 2(2): 75-82.

Lumpkin, S.A. (1987) Repurchase and Reverse Repurchase Agreements. *Federal Reserve Bank of Richmond, Economic Review* 73(1): 15-23.

Lustig, H., Roussanov, N. and Verdelhan, A. (2011) Common Risk Factors in Currency Markets. *Review of Financial Studies* 24(11): 3731-3777.

Lustig, H., Roussanov, N. and Verdelhan, A. (2014) Countercyclical currency risk premia. *Journal of Financial Economics* 111(3): 527-553.

Lustig, H. and Verdelhan, A. (2007) The Cross-Section of Foreign Currency Risk Premia and US Consumption Growth Risk. *American Economic Review* 97(1): 89-117.

Ma, K., Mercer, M. and Walker, M. (1992) Rolling over futures contracts: A note. *Journal of Futures Markets* 12(2): 203-217.

Maaravi, Y. and Levy, A. (2017) When your anchor sinks your boat: Information asymmetry in distributive negotiations and the disadvantage of making the first offer. *Judgment and Decision Making* 12(5): 420-429.

Macaulay, F.R. (1938) *Some theoretical problems suggested by the movements of interest rates, bond yields and stock prices in the United States since 1856.* New York, NY: NBER, Inc.

MacKinnon, G.H. and Al Zaman, A. (2009) Real estate for the long term: the effect of return predictability on long-horizon allocations. *Real Estate Economics* 37(1): 117-153.

Mackintosh, P. (2017) It's all about active ETFs. *Journal of Index Investing* 7(4): 6-15.

Madhavan, A. (2012) Exchange-Traded Funds, Market Structure, and the Flash Crash. *Financial Analysts Journal* 68(4): 20-35.

Madhavan, A.N. (2016) *Exchange-Traded Funds and the New Dynamics of Investing.* Oxford, UK: Oxford University Press.

Madura, J. and Ngo, T. (2008) Impact of ETF inception on the valuation and trading of component stocks. *Applied Financial Economics* 18(12): 995-1007.

Maghrebi, N., Kim, M. and Nishina, K. (2007) The KOSPI200 Implied Volatility Index: Evidence of Regime Shifts in Expected Volatility. *Asia-Pacific Journal of Financial Studies* 36(2): 163-187.

Maheswaran, K. and Yeoh, S.C. (2005) The Profitability of Merger Arbitrage: Some Australian Evidence. *Australian Journal of Management* 30(1): 111-126.

Malizia, E.E. and Simons, R.A. (1991) Comparing Regional Classifications for Real Estate Portfolio Diversification. *Journal of Real Estate Research* 6(1): 53-77.

Malkiel, B.G. (2014) Is Smart Beta Really Smart? *Journal of Portfolio Management* 40(5): 127-134.

Malpezzi, S. (1999) A Simple Error Correction Model of House Prices. *Journal of Housing Economics* 8(1): 27-62.

Maluf, Y.S. and Albuquerque, P.H.M. (2013) Empirical evidence: arbitrage with Exchange-traded Funds (ETFs) on the Brazilian market. *Revista Contabilidade & Finanças* 24(61): 64-74.

Mancini-Griffoli, T. and Ranaldo, A. (2011) Limits to Arbitrage During the Crisis: Funding Liquidity Constraints and Covered Interest Parity. *Working Paper.* Available online: `https://ssrn.com/abstract=1549668`.

Mankiw, N.G. and Summers, L.H. (1984) Do Long-Term Interest Rates Overreact to Short-Term Interest Rates? *Brookings Papers on Economic Activity*, No. 1, pp. 223-242.

Mann, S.V. and Ramanlal, P. (1997) The relative performance of yield curve strategies. *Journal of Portfolio Management* 23(4): 64-70.

Manoliu, M. (2004) Storage options valuation using multilevel trees and calendar spreads. *International Journal of Theoretical and Applied Finance* 7(4): 425-464.

Maribu, K.M., Galli, A. and Armstrong, M. (2007) Valuation of spark-spread options with mean reversion and stochastic volatility. *International Journal of Electronic Business Management* 5(3): 173-181.

Mark, N.C. and Wu, Y. (2001) Rethinking Deviations From Uncovered Interest Parity: the Role of Covariance Risk and Noise. *Economic Journal* 108(451): 1686-1706.

Markowitz, H. (1952) Portfolio Selection. *Journal of Finance* 7(1): 77-91.

Markwardt, D., Lopez, C. and DeVol, R. (2016) The Economic Impact of Chapter 11 Bankruptcy versus Out-of-Court Restructuring. *Journal of Applied Corporate Finance* 28(4): 124-128.

Marques, C.R., Neves, P.D. and Sarmento, L.M. (2003) Evaluating core inflation indicators. *Economic Modelling* 20(4): 765-775.

Marshall, C.M. (2008) *Volatility trading: Hedge funds and the search for alpha (new challenges to the efficient markets hypothesis)* (Ph.D. Thesis). New York, NY: Fordham University. Available online: `https://fordham.bepress.com/dissertations/AAI3353774/`.

Marshall, C.M. (2009) Dispersion trading: Empirical evidence from U.S. options markets. *Global Finance Journal* 20(3): 289-301.

Marshall, B.R., Cahan, R.H. and Cahan, J.M. (2008) Can commodity futures be profitably traded with quantitative market timing strategies? *Journal of Banking & Finance* 32(9): 1810-1819.

Marshall, B.R., Nguyen, N.H. and Visaltanachoti, N. (2013) ETF arbitrage: Intraday evidence. *Journal of Banking & Finance* 37(9): 3486-3498.

Martellini, L., Milhau, V. and Tarelli, A. (2015) Hedging Inflation-Linked Liabilities without Inflation-Linked Instruments through Long/Short Investments in Nominal Bonds. *Journal of Fixed Income* 24(3): 5-29.

Martellini, L., Priaulet, P. and Priaulet, S. (2002) Understanding the butterfly strategy. *Journal of Bond Trading and Management* 1(1): 9-19.

Martellini, L., Priaulet, P. and Priaulet, S. (2003) *Fixed Income Securities: Valuation, Risk Management and Portfolio Strategies.* Hoboken, NJ: John Wiley & Sons, Inc.

Martin, G. (2010) The Long-Horizon Benefits of Traditional and New Real Assets in the Institutional Portfolio. *Journal of Alternative Investments* 13(1): 6-29.

Martin, I. (2011) Simple Variance Swaps. *Working Paper.* Available online: http://www.nber.org/papers/w16884.

Martinelli, R. and Rhoads, N. (2010) Predicting Market Data Using The Kalman Filter, Part 1 and Part 2. *Technical Analysis of Stocks & Commodities* 28(1): 44-47; *ibid.* 28(2): 46-51.

Martínez, B. and Torró, H. (2018) Hedging spark spread risk with futures. *Energy Policy* 113: 731-746.

Maslov, S. and Zhang, Y.-C. (1998) Optimal investment strategy for risky assets. *International Journal of Theoretical and Applied Finance* 1(3): 377-387.

Matsypura, D. and Timkovsky, V.G. (2010) Combinatorics of Option Spreads: The Margining Aspect. *Working Paper.* Available online: https://ses.library.usyd.edu.au/bitstream/2123/8172/1/OMWP_2010_04.pdf.

Mauer, R. and Sebastian, S. (2002) Inflation Risk Analysis of European Real Estate Securities. *Journal of Real Estate Research* 24(1): 47-78.

Mayers, D. (1998) Why firms issue convertible bonds: The matching of financial and real investment options. *Journal of Financial Economics* 47(1): 83-102.

Mayhew, S. (1995) Implied Volatility. *Financial Analysts Journal* 51(4): 8-20.

Maze, S. (2012) Dispersion Trading in South Africa: An Analysis of Profitability and a Strategy Comparison. *Working Paper.* Available online: https://ssrn.com/abstract=2398223.

Mazurczak, A. (2011) Development of Real Estate Investment Trust (REIT) regimes in Europe. *Journal of International Studies* 4(1): 115-123.

McCants, A. (2007) Goods at Pawn: The Overlapping Worlds of Material Possessions and Family Finance in Early Modern Amsterdam. *Social Science History* 31(2): 213-238.

McComas, A. (2003) Getting technical with spreads. *Futures Magazine*, July 2013, pp. 52-55.

McConnell, J.J. and Buser, S.A. (2011) The Origins and Evolution of the Market for Mortgage-Backed Securities. *Annual Review of Financial Economics* 3: 173-192.

McConnell, J.J. and Schwartz, E.S. (1986) LYON Taming. *Journal of Finance* 41(3): 561-577.

McDevitt, D. and Kirwan, J. (2008) Corporate and Infrastructure-backed Inflation-linked Bonds. In: Benaben, B. and Goldenberg, S. (eds.) *Inflation Risk and Products: The Complete Guide.* London, UK: Risk Books, pp. 621-641.

McDonald, R.L. (2001) Cross-Border Investing with Tax Arbitrage: The Case of German Dividend Tax Credits. *Review of Financial Studies* 14(3): 617-657.

Mcelroy, T. (2008) Exact formulas for the Hodrick-Prescott Filter. *Econometrics Journal* 11(1): 208-217.

McEnally, R.W. and Rice, M.L. (1979) Hedging Possibilities in the Flotation of Debt Securities. *Financial Management* 8(4): 12-18.

McKee, T.E. and Lensberg, T. (2002) Genetic programming and rough sets: A hybrid approach to bankruptcy classification. *European Journal of Operational Research* 138(2): 436-451.

McKenzie, J.A. (2002) A Reconsideration of the Jumbo/Non-Jumbo Mortgage Rate Differential. *Journal of Real Estate Finance and Economics* 25(2-3): 197-213.

McMillan, L.G. (2002) *Options as a Strategic Investment.* (4th ed.) New York, NY: New York Institute of Finance.

Meen, G. (2002) The Time-Series Behavior of House Prices: A Transatlantic Divide? *Journal of Housing Economics* 11(1): 1-23.

Mehra, Y.P. (2002) Survey Measures of Expected Inflation: Revisiting the Issues of Predictive Content and Rationality. *Federal Reserve Bank of Richmond, Economic Quarterly* 88(3): 17-36.

Mei, J. and Gao, B. (1995) Price Reversals, Transaction costs and Arbitrage Profits in the Real Estate Securities Market. *Journal of Real Estate Finance and Economics* 11(2): 153-165.

Mei, J. and Liao, H.H. (1998) Risk Characteristics of Real Estate Related Securities: An Extension of Liu and Mei (1992). *Journal of Real Estate Research* 16(3): 279-290.

Meissner, G. (ed.) (2008) *The Definitive Guide to CDOs.* London, UK: Incisive Media.

Meissner, G. (2016) Correlation Trading Strategies: Opportunities and Limitations. *Journal of Trading* 11(4): 14-32.

Mendenhall, R. (2004) Arbitrage Risk and the Post-Earnings-Announcement Drift. *Journal of Business* 77(6): 875-894.

Menkhoff, L., Sarno, L., Schmeling, M. and Schrimpf, A. (2012) Currency momentum strategies. *Journal of Financial Economics* 106(3): 660-684.

Menkveld, A.J. (2013) High Frequency Trading and the New Market Makers. *Journal of Financial Markets* 16(4): 712-740.

Menkveld, A.J. (2016) The Economics of High-Frequency Trading: Taking Stock. *Annual Review of Financial Economics* 8: 1-24.

Mercurio, F. (2005) Pricing inflation-indexed derivatives. *Quantitative Finance* 5(3): 289-302.

Mercurio, F. and Moreni, N. (2006) Inflation with a smile. *Risk* 19(3): 70-75.

Mercurio, F. and Moreni, N. (2009) Inflation modelling with SABR dynamics. *Risk*, June 2009, pp. 106-111.

Mercurio, F. and Yildirim, Y. (2008) Modelling Inflation. In: Benaben, B. and Goldenberg, S. (eds.) *Inflation Risks and Products: The Complete Guide.* London, UK: Risk Books.

Merton, R.C. (1987) A Simple Model of Capital Market Equilibrium with Incomplete Information. *Journal of Finance* 42(3): 483-510.

Metghalchi, M., Marcucci, J. and Chang, Y.-H. (2012) Are moving average trading rules profitable? Evidence from the European stock markets. *Applied Economics* 44(12): 1539-1559.

Meziani, A.S. (2015) Active exchange-traded funds: Are we there yet? *Journal of Index Investing* 6(2): 86-98.

Mhaskar, H.N. and Micchelli, C.A. (1993) How to choose an activation function. In: *Proceedings of the 6th International Conference on Neural Information Processing Systems (NIPS'93).* San Francisco, CA: Morgan Kaufmann Publishers, Inc., pp. 319-326.

Miao, G.J. (2014) High frequency and dynamic pairs trading based on statistical arbitrage using a two-stage correlation and cointegration approach. *International Journal of Economics and Finance* 6(3): 96-110.

Miao, G.J., Wei, B. and Zhou, H. (2012) Ambiguity Aversion and Variance Premium. *Working Paper.* Available online: https://ssrn.com/abstract=2023765.

Miffre, J. (2012) Hedging pressure-based long/short commodity strategy used for third generation commodity index. *Risk*, January 2012. Available online: https://www.risk.net/2247251.

Miffre, J. and Rallis, G. (2007) Momentum strategies in commodity futures markets. *Journal of Banking & Finance* 31(6): 1863-1886.

Milanov, K., Kounchev, O., Fabozzi, F.J., Kim, Y.S. and Rachev, S.T. (2013) A Binomial-Tree Model for Convertible Bond Pricing. *Journal of Fixed Income* 22(3): 79-94.

Miles, M. and Mahoney, J. (1997) Is commercial real estate an inflation hedge? *Real Estate Finance* 13(4): 31-45.

Miles, M. and McCue, T. (1984) Commercial Real Estate Returns. *Real Estate Economics* 12(3): 355-377.

Miller, M.H. (1977) Debt and taxes. *Journal of Finance* 32(2): 261-275.

Milonas, N.T. (1991) Measuring seasonalities in commodity markets and the half-month effect. *Journal of Futures Markets* 11(3): 331-346.

Milosevic, N. (2016) Equity Forecast: Predicting Long Term Stock Price Movement using Machine Learning. *Journal of Economics Library* 3(2): 288-294.

Miltersen, K.R. and Schwartz, E.S. (1998) Pricing of options on commodity futures with stochastic term structures of convenience yield and interest rates. *Journal of Financial and Quantitative Analysis* 33(1): 33-59.

Min, S., Lee, J. and Han, I. (2006) Hybrid genetic algorithms and support vector machines for bankruptcy prediction. *Expert Systems with Applications* 31(3): 652-660.

Minton, B.A. (1997) An empirical examination of basic valuation models for plain vanilla U.S. interest rate swaps. *Journal of Financial Economics* 44(2): 251-277.

Mitchell, M. and Pulvino, T. (2001) Characteristics of Risk and Return in Risk Arbitrage. *Journal of Finance* 56(6): 2135-2175.

Mittal, A. and Goel, A. (2012) Stock Prediction Using Twitter Sentiment Analysis. *Working Paper.* Palo Alto, CA: Stanford University.

Mitton, T. and Vorkink, K. (2007) Equilibrium Underdiversification and the Preference for Skewness. *Review of Financial Studies* 20(4): 1255-1288.

Mixon, S. (2007) The implied volatility term structure of stock index options. *Journal of Empirical Finance* 14(3): 333-354.

Mixon, S. (2011) What Does Implied Volatility Skew Measure? *Journal of Derivatives* 18(4): 9-25.

Mladina, P. (2014) Dynamic Asset Allocation with Horizon Risk: Revisiting Glide Path Construction. *Journal of Wealth Management* 16(4): 18-26.

Monkhouse, P.H.L. (1993) The Cost of Equity Under the Australian Dividend Imputation Tax System. *Accounting and Finance* 33(2): 1-18.

Monoyios, M. (2004) Performance of Utility-Based Strategies for Hedging Basis Risk. *Quantitative Finance* 4(3): 245-255.

Monoyios, M. and Sarno, L. (2002) Mean reversion in stock index futures markets: a nonlinear analysis. *Journal of Futures Markets* 22(4): 285-314.

Montelongo, A. and Chang, H.K. (2008) *Flip and grow rich: The heart and mind of real estate investing.* San Antonio, TX: Armondo Montelongo Worldwide, Inc.

Montrucchio, L. and Peccati, L. (1991) A note on Shiu-Fisher-Weil immunization theorem. *Insurance: Mathematics and Economics* 10(2): 125-131.

Moore, S., Toepke, J. and Colley, N. (2006) *The encyclopedia of commodity and financial spreads.* Hoboken, NJ: John Wiley & Sons, Inc.

Moosa, I. (2001) Triangular Arbitrage in the Spot and Forward Foreign Exchange Markets. *Quantitative Finance* 1(4): 387-390.

Moosa, I.A. (2003a) Two-Currency, Three-Currency and Multi-Currency Arbitrage. In: *International Financial Operations: Arbitrage, Hedging, Speculation, Financing and Investment.* Finance and Capital Markets Series. London, UK: Palgrave Macmillan, Chapter 1, pp. 1-18.

Moosa, I.A. (2003b) The sensitivity of the optimal hedge ratio to model specification. *Finance Letters* 1(1): 15-20.

Moran, M.T. and Dash, S. (2007) VIX Futures and Options: Pricing and Using Volatility Products to Manage Downside Risk and Improve Efficiency in Equity Portfolios. *Journal of Trading* 2(3): 96-105.

Morisawa, Y. (2009) Toward a Geometric Formulation of Triangular Arbitrage: An Introduction to Gauge Theory of Arbitrage. *Progress of Theoretical Physics Supplement* 179: 209-215.

Morse, D. and Shaw, W. (1988) Investing in Bankrupt Firms. *Journal of Finance* 43(5): 1193-1206.

Moskowitz, T.J. and Grinblatt, M. (1999) Do Industries Explain Momentum? *Journal of Finance* 54(4): 1249-1290.

Moskowitz, T.J., Ooi, Y.H. and Pedersen, L.H. (2012) Time Series Momentum. *Journal of Financial Economics* 104(2): 228-250.

Moss, A., Clare, A., Thomas, S. and Seaton, J. (2015) Trend Following and Momentum Strategies for Global REITs. *Journal of Real Estate Portfolio Management* 21(1): 21-31.

Mossman, C.E., Bell, G.G., Swartz, L.M. and Turtle, H. (1998) An empirical comparison of bankruptcy models. *Financial Review* 33(2): 35-54.

Mou, Y. (2010) Limits to Arbitrage and Commodity Index Investment: Front-Running the Goldman Roll. *Working Paper.* Available online: `https://ssrn.com/abstract=1716841`.

Mouakhar, T. and Roberge, M. (2010) The Optimal Approach to Futures Contract Roll in Commodity Portfolios. *Journal of Alternative Investments* 12(3): 51-60.

Moyer, S.G., Martin, D. and Martin, J. (2012) A Primer on Distressed Investing: Buying Companies by Acquiring Their Debt. *Journal of Applied Corporate Finance* 24(4): 59-76.

Mraoua, M. (2007) Temperature stochastic modelling and weather derivatives pricing: empirical study with Moroccan data. *Afrika Statistika* 2(1): 22-43.

Mueller, G.R. (1993) Refining Economic Diversification Strategies for Real Estate Portfolios. *Journal of Real Estate Research* 8(1): 55-68.

Mueller, G.R. and Laposa, S.P. (1995) Property-Type Diversification in Real Estate Portfolios: A Size and Return Perspective. *Journal of Real Estate Portfolio Management* 1(1): 39-50.

Mueller, A. and Mueller, G. (2003) Public and Private Real Estate in a Mixed-Asset Portfolio. *Journal of Real Estate Portfolio Management* 9(3): 193-203.

Mugwagwa, T., Ramiah, V., Naughton, T. and Moosa, I. (2012) The efficiency of the buy-write strategy: Evidence from Australia. *Journal of International Financial Markets, Institutions and Money* 22(2): 305-328.

Müller, A. and Grandi, M. (2000) Weather Derivatives: A Risk Management Tool for Weather-sensitive Industries. *Geneva Papers on Risk and Insurance* 25(2): 273-287.

Mun, K.-C. (2016) Hedging bank market risk with futures and forwards. *Quarterly Review of Economics and Finance* 61: 112-125.

Mun, K.-C. and Morgan, G.E. (1997) Cross-hedging foreign exchange rate risks: The case of deposit money banks in emerging Asian countries. *Pacific-Basin Finance Journal* 5(2): 215-230.

Mun, J.C., Vasconcellos, G.M. and Kish, R. (2000) The contrarian overreaction hypothesis: An analysis of the US and Canadian stock markets. *Global Finance Journal* 11(1-2): 53-72.

Murphy, J.J. (1986) *Technical analysis of the futures markets: A comprehensive guide to trading methods and applications.* New York, NY: New York Institute of Finance.

Muthuswamy, J., Palmer, J., Richie, N. and Webb, R. (2011) High-Frequency Trading: Implications for Markets, Regulators, and Efficiency. *Journal of Trading* 6(1): 87-97.

Mwangi, C.I. and Duncan, M.O. (2012) An investigation into the existence of exchange rate arbitrage in the Mombasa spot market. *International Journal of Humanities and Social Science* 2(21): 182-196.

Myers, R.J. (1991) Estimating time-varying optimal hedge ratios on futures markets. *Journal of Futures Markets* 11(1): 39-53.

Nakamoto, S. (2008) Bitcoin: A Peer-to-Peer Electronic Cash System. *Working Paper.* Available online: `https://bitcoin.org/bitcoin.pdf`.

Nakano, M., Takahashi, A. and Takahashi, S. (2018) Bitcoin Technical Trading With Artificial Neural Network. *Working Paper.* Available online: `https://ssrn.com/abstract=3128726`.

Nandy (Pal), S. and Chattopadhyay, A.Kr. (2016) Impact of Individual Stock Derivatives Introduction in India on Its Underlying Spot Market Volatility. *Asia-Pacific Journal of Management Research and Innovation* 12(2): 109-133.

Nartea, G. and Eves, C. (2010) Role of farm real estate in a globally diversified asset portfolio. *Journal of Property Investment & Finance* 28(3): 198-220.

Nashikkar, A., Subrahmanyam, M.G. and Mahanti, S. (2011) Liquidity and Arbitrage in the Market for Credit Risk. *Journal of Financial and Quantitative Analysis* 46(3): 627-656.

Nawalkha, S.K. and Chambers, D.R. (1996) An improved immunization strategy: M-absolute. *Financial Analysts Journal* 52(5): 69-76.

Nekrasov, V. (2014) Kelly Criterion for Multivariate Portfolios: A Model-Free Approach. *Working Paper.* Available online: https://ssrn.com/abstract=2259133.

Nelken, I. (2006) Variance swap volatility dispersion. *Derivatives Use, Trading & Regulation* 11(4): 334-344.

Nelling, E. and Gyourko, J. (1998) The Predictability of Equity REIT Returns. *Journal of Real Estate Research* 16(3): 251-268.

Newell, G. (1996) The inflation-hedging characteristics of Australian commercial property: 1984-1995. *Journal of Property Finance* 7(1): 6-20.

Newell, G., Chau, K.W. and Wong, S.K. (2009) The significance and performance of infrastructure in China. *Journal of Property Investment & Finance* 27(2): 180-202.

Newell, G. and Peng, H.W. (2008) The role of US infrastructure in investment portfolios. *Journal of Real Estate Portfolio Management* 14(1): 21-34.

Newell, G., Peng, H.W. and De Francesco, A. (2011) The performance of unlisted infrastructure in investment portfolios. *Journal of Property Research* 28(1): 59-74.

Ng, K.Y. and Phelps, B.D. (2015) The Hunt for a Low-Risk Anomaly in the USD Corporate Bond Market. *Journal of Portfolio Management* 42(1): 63-84.

Ng, V.K. and Pirrong, S.C. (1994) Fundamentals and volatility: storage, spreads, and the dynamics of metals prices. *Journal of Business* 67(2): 203-230.

Ng, J., Rusticus, T. and Verdi, R. (2008) Implications of Transaction Costs for the Post-Earnings Announcement Drift. *Journal of Accounting Research* 46(3): 661-696.

Nguyen, V.T.T. and Sercu, P. (2010) Tactical Asset Allocation with Commodity Futures: Implications of Business Cycle and Monetary Policy. *Working Paper.* Available online: https://ssrn.com/abstract=1695889.

Niblock, S.J. (2017) Flight of the Condors: Evidence on the Performance of Condor Option Spreads in Australia. *Applied Finance Letters* 6(1): 38-53.

Nielsen, M.J. and Schwartz, E.S. (2004) Theory of storage and the pricing of commodity claims. *Review of Derivatives Research* 7(1): 5-24.

Nisar, T.M. and Yeung, M. (2018) Twitter as a tool for forecasting stock market movements: A short-window event study. *Journal of Finance and Data Science* 4(2): 101-119.

Noh, J., Engle, R.F. and Kane, A. (1994) Forecasting volatility and option prices of the S&P500 Index. *Journal of Derivatives* 2(1): 17-30.

Nossman, M. and Wilhelmsson, A. (2009) Is the VIX Futures Market Able to Predict the VIX Index? A Test of the Expectation Hypothesis. *Journal of Alternative Investments* 12(2): 54-67.

Nothaft, F.E., Lekkas, V. and Wang, G.H.K. (1995) The Failure of the Mortgage-Backed Futures Contract. *Journal of Futures Markets* 15(5): 585-603.

Novak, M.G. and Velušçek, D. (2016) Prediction of stock price movement based on daily high prices. *Quantitative Finance* 16(5): 793-826.

Novy-Marx, R. (2009) Hot and Cold Markets. *Real Estate Economics* 37(1): 1-22.

Novy-Marx, R. (2013) The other side of value: The gross profitability premium. *Journal of Financial Economics* 108(1): 1-28.

Nyaradi, J. (2010) *Super Sectors: How to Outsmart the Market Using Sector Rotation and ETFs.* Hoboken, NJ: John Wiley & Sons, Inc.

Odean, T. (2002) Volume, Volatility, Price, and Profit When All Traders Are Above Average. *Journal of Finance* 53(6): 1887-1934.

O'Doherty, M.S. (2012) On the Conditional Risk and Performance of Financially Distressed Stocks. *Management Science* 58(8): 1502-1520.

Odom, M.D. and Sharda, R. (1990) A neural network model for bankruptcy prediction. In: *Proceedings of the International Joint Conference on Neural Networks*, Vol. 2. Washington, DC: IEEE, pp. 163-168.

Oetomo, T. and Stevenson, M. (2005) Hot or cold? A comparison of different approaches to the pricing of weather derivatives. *Journal of Emerging Market Finance* 4(2): 101-133.

Officer, M.S. (2004) Collars and renegotiation in mergers and acquisitions. *Journal of Finance* 59(6): 2719-2743.

Officer, M.S. (2006) The market pricing of implicit options in merger collars. *Journal of Business* 79(1): 115-136.

O'Hara, M. (2015) High frequency market microstructure. *Journal of Financial Economics* 116(2): 257-270.

Ohlson, J.A. (1980) Financial Ratios and the Probabilistic Prediction of Bankruptcy. *Journal of Accounting Research* 18(1): 109-131.

Okunev, J. and White, D. (2003) Do Momentum-Based Strategies Still Work in Foreign Currency Markets? *Journal of Financial and Quantitative Analysis* 38(2): 425-447.

Olmo, J. and Pilbeam, K. (2009) The profitability of carry trades. *Annals of Finance* 5(2): 231-241.

Olszweski, F. and Zhou, G. (2013) Strategy diversification: Combining momentum and carry strategies within a foreign exchange portfolio. *Journal of Derivatives & Hedge Funds* 19(4): 311-320.

O'Neal, E.S. (2000) Industry Momentum and Sector Mutual Funds. *Financial Analysts Journal* 56(4): 37-49.

Opler, T., Pinkowitz, L., Stulz, R. and Williamson, R. (1999) The determinants and implications of corporate cash holdings. *Journal of Financial Economics* 52(1): 3-46.

Opp, C.C. (2017) Learning, Optimal Default, and the Pricing of Distress Risk. *Working Paper.* Available online: `https://ssrn.com/abstract=2181441`.

Ortalo-Magné, F. and Rady, S. (2006) Housing Market Dynamics: On the Contribution of Income Shocks and Credit Constraints. *Review of Economic Studies* 73(2): 459-485.

Ortisi, M. (2016) Bitcoin Market Volatility Analysis Using Grand Canonical Minority Game. *Ledger* 1: 111-118.

Osborne, M.J. (2005) On the computation of a formula for the duration of a bond that yields precise results. *Quarterly Review of Economics and Finance* 45(1): 161-183.

Osler, C.L. (2000) Support for Resistance: Technical Analysis and Intraday Exchange Rates. *Federal Reserve Bank of New York, Economic Policy Review* 6(2): 53-68.

Osler, C.L. (2003) Currency Orders and Exchange Rate Dynamics: An explanation for the predictive success of Technical Analysis. *Journal of Finance* 58(5): 1791-1819.

Osteryoung, J.S., McCarty, D.E. and Roberts, G.S. (1981) Riding the Yield Curve with Treasury Bills. *Financial Review* 16(3): 57-66.

Osu, B.O. (2010) Currency Cross Rate and Triangular Arbitrage in Nigerian Exchange Market. *International Journal of Trade, Economics and Finance* 1(4): 345-348.

O'Tool, R. (2013) The Black-Litterman model: A risk budgeting perspective. *Journal of Asset Management* 14(1): 2-13.

Ou, P. and Wang, H. (2009) Prediction of stock market index movement by ten data mining techniques. *Modern Applied Science* 3(12): 28-42.

Oyedele, J.B., Adair, A. and McGreal, S. (2014) Performance of global listed infrastructure investment in a mixed asset portfolio. *Journal of Property Research* 31(1): 1-25.

Ozdagli, A.K. (2010) The Distress Premium Puzzle. *Working Paper.* Available online: `https://ssrn.com/abstract=1713449`.

Oztekin, A.S., Mishra, S., Jain, P.K., Daigler, R.T., Strobl, S. and Holowczak, R.D. (2017) Price Discovery and Liquidity Characteristics for U.S. Electronic Futures and ETF Markets. *Journal of Trading* 12(2): 59-72.

Packer, F. and Zhu, H. (2005) Contractual terms and CDS pricing. *BIS Quarterly Review*, March 2005, pp. 89-100. Available online: `https://www.bis.org/publ/qtrpdf/r_qt0503h.pdf`.

Pagnotta, E. and Philippon, T. (2012) Competing on Speed. *Working Paper.* Available online: `https://ssrn.com/abstract=1972807`.

Pagolu, V.S., Reddy, K.N., Panda, G. and Majhi, B. (2016) Sentiment analysis of Twitter data for predicting stock market movements. In: *Proceedings of the 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES).* Washington, DC: IEEE, pp. 1345-1350.

Pagonidis, A.S. (2014) The IBS Effect: Mean Reversion in Equity ETFs. *Working Paper.* Available online:
`http://www.naaim.org/wp-content/uploads/2014/04/00V_Alexander_Pagonidis_The-IBS-Effect-Mean-Reversion-in-Equity-ETFs-1.pdf`.

Pan, J. and Poteshman, A.M. (2006) The Information in Option Volume for Future Stock Prices. *Review of Financial Studies* 19(3): 871-908.

Panayiotou, A. and Medda, F.R. (2014) Attracting Private Sector Participation in Transport Investment. *Procedia – Social and Behavioral Sciences* 111: 424-431.

Panayiotou, A. and Medda, F. (2016) Portfolio of Infrastructure Investments: Analysis of European Infrastructure. *Journal of Infrastructure Systems* 22(3): 04016011.

Pantalone, C. and Platt, H. (1984) Riding the Yield Curve. *Journal of Financial Education*, No. 13, pp. 5-9.

Papageorgiou, N.A., Reeves, J.J. and Sherris, M. (2017) Equity investing with targeted constant volatility exposure. *Working Paper.* Available online: https://ssrn.com/abstract=2614828.

Park, K., Jung, M. and Lee, S. (2018) Credit ratings and convertible bond prices: a simulation-based valuation. *European Journal of Finance* 24(12): 1001-1025.

Parnaudeau, M. and Bertrand, J.-L. (2018) The contribution of weather variability to economic sectors. *Applied Economics* 50(43): 4632-4649.

Pascalau, R. and Poirier, R. (2015) Bootstrapping the Relative Performance of Yield Curve Strategies. *Journal of Investment Strategies* 4(2): 55-81.

Paschke, R. and Prokopczuk, M. (2012) Investing in commodity futures markets: can pricing models help? *European Journal of Finance* 18(1): 59-87.

Passmore, W., Sherlund, S.M. and Burgess, G. (2005) The Effect of Housing Government-Sponsored Enterprises on Mortgage Rates. *Real Estate Economics* 33(3): 427-463.

Pástor, L'. and Stambaugh, R.F. (2003) Liquidity Risk and Expected Stock Returns. *Journal of Political Economy* 111(3): 642-685.

Pätäri, E. and Vilska, M. (2014) Performance of moving average trading strategies over varying stock market conditions: the Finnish evidence. *Applied Economics* 46(24): 2851-2872.

Pelaez, R.F. (1997) Riding the yield curve: Term premiums and excess returns. *Review of Financial Economics* 6(1): 113-119.

Peng, H.W. and Newell, G. (2007) The Significance of Infrastructure in Australian Investment Portfolios. *Pacific Rim Property Research Journal* 13(4): 423-450.

Pennacchi, G.G. (1991) Identifying the Dynamics of Real Interest Rates and Inflation: Evidence Using Survey Data. *Review of Financial Studies* 4(1): 53-86.

Pepić, M. (2014) Managing interest rate risk with interest rate futures. *Ekonomika preduzeća* 62(3-4): 201-209.

Perchanok, K. (2012) *Futures spreads: theory and praxis* (Ph.D. Thesis). Northampton, UK: The University of Northampton. Available online: http://nectar.northampton.ac.uk/4963/1/Perchanok20124963.pdf.

Perchanok, K. and Kakabadse, N. (2013) Causes of Market Anomalies of Crude Oil Calendar Spreads: Does Theory of Storage Address the Issue? *Problems and Perspectives in Management* 11(2): 35-47.

Perchet, R., de Carvalho, R.L. and Moulin, P. (2014) Intertemporal risk parity: a constant volatility framework for factor investing. *Journal of Investment Strategies* 4(1): 19-41.

Perez-Gonzalez, F. and Yun, H. (2010) Risk Management and Firm Value: Evidence from Weather Derivatives. *Working Paper.* Available online: https://ssrn.com/abstract=1357385.

Perić, M.R. (2015) *Ekonomski aspekti korporativnih bankrotstava i stečajnih procesa.* Belgrade, Serbia: Modern Business School.

Perlin, M.S. (2009) Evaluation of pairs-trading strategy at the Brazilian financial market. *Journal of Derivatives & Hedge Funds* 15(2): 122-136.

Person, J.L. (2007) *Candlestick and Pivot Point Trading Triggers.* Hoboken, NJ: John Wiley & Sons, Inc.

Peterson, J.D. and Hsieh, C.-H. (1997) Do Common Risk Factors in the Returns on Stocks and Bonds Explain Returns on REITs? *Real Estate Economics* 25(2): 321-345.

Petre, G. (2015) A Case for Dynamic Asset Allocation for Long Term Investors. *Procedia Economics and Finance* 29: 41-55.

Pflueger, C.E. and Viceira, L.M. (2011) Inflation-Indexed Bonds and the Expectations Hypothesis. *Annual Review of Financial Economics* 3: 139-158.

Philosophov, L.V. and Philosophov, V.L. (2005) Optimization of a firm's capital structure: A quantitative approach based on a probabilistic prognosis of risk and time of bankruptcy. *International Review of Financial Analysis* 14(2): 191-209.

Piazzesi, M. and Schneider, M. (2009) Momentum Traders in the Housing Market: Survey Evidence and a Search Model. *American Economic Review* 99(2): 406-411.

Picou, G. (1981) Managing Interest Rate Risk with Interest Rate Futures. *Bankers Magazine*, Vol. 164, May-June 1981, pp. 76-81.

Pindado, J., Rodrigues, L. and de la Torre, C. (2008) Estimating financial distress likelihood. *Journal of Business Research* 61(9): 995-1003.

Pindyck, R.S. (2001) The dynamics of commodity spot and futures markets: a primer. *Energy Journal* 22(3): 1-30.

Piotroski, J.D. (2000) Value investing: The use of historical financial statement information to separate winners from losers. *Journal of Accounting Research* 38: 1-41.

Piotroski, J.D. and So, E.C. (2012) Identifying Expectation Errors in Value/ Glamour Strategies: A Fundamental Analysis Approach. *Review of Financial Studies* 25(9): 2841-2875.

Pirrong, C. (2005) Momentum in Futures Markets. *Working Paper.* Available online: `https://ssrn.com/abstract=671841`.

Pirrong, C. (2017) The economics of commodity market manipulation: A survey. *Journal of Commodity Markets* 5: 1-17.

Pisani, B. (2010) Man Vs. Machine: How Stock Trading Got So Complex. *CNBC* (September 13, 2010). Available online: `https://www.cnbc.com/id/38978686`.

Pitts, M. (1985) The Management of Interest Rate Risk: Comment. *Journal of Portfolio Management* 11(4): 67-69.

Pivar, W. (2003) *Real Estate Investing From A to Z: The Most Comprehensive, Practical, and Readable Guide to Investing Profitably in Real Estate.* New York, NY: McGraw-Hill, Inc.

Pizzutilo, F. (2013) A note on the effectiveness of pairs trading for individual investors. *International Journal of Economics and Financial Issues* 3(3): 763-771.

Podobnik, B., Horvatic, D., Petersen, A.M., Urošević, B. and Stanley, H.E. (2010) Bankruptcy risk model and empirical tests. *Proceedings of the National Academy of Sciences* 107(43): 18325-18330.

Poitras, G. (1990) The distribution of gold futures spreads. *Journal of Futures Markets* 10(6): 643-659.

Pole, A. (2007) *Statistical arbitrage: algorithmic trading insights and techniques.* Hoboken, NJ: John Wiley & Sons, Inc.

Popper, H. (1993) Long-term covered interest parity: evidence from currency swaps. *Journal of International Money and Finance* 12(4): 439-448.

Porter, M.F. (1980) An Algorithm for Suffix Stripping. *Program* 14(3): 130-137.

Poterba, J. (1986) Explaining the yield spread between taxable and tax exempt bonds. In: Rosen, H. (ed.) *Studies in State and Local Public Finance.* Chicago, IL: University of Chicago Press, pp. 5-48.

Poterba, J. (1989) Tax reform and the market for tax-exempt debt. *Regional Science and Urban Economics* 19(3): 537-562.

Poterba, J. and Sinai, T. (2008) Tax Expenditures for Owner-Occupied Housing: Deductions for Property Taxes and Mortgage Interest and the Exclusion of Imputed Rental Income. *American Economic Review* 98(2): 84-89.

Poterba, J.M. and Summers, L.H. (1988) Mean reversion in stock prices: evidence and implications. *Journal of Financial Economics* 22(1): 27-59.

Potjer, D. and Gould, C. (2007) *Global Tactical Asset Allocation: Exploiting the opportunity of relative movements across asset classes and financial markets.* London, UK: Risk Books.

Pounds, H. (1978) Covered Call Option Writing Strategies and Results. *Journal of Portfolio Management* 4(2): 31-42.

Prince, J.T. (2005) Investing in Collateralized Debt Obligations. *CFA Institute Conference Proceedings* 2005(1): 52-61.

Pring, M.J. (1985) *Technical analysis explained: The successful investor's guide to spotting investment trends and turning points.* (3rd ed.) New York, NY: McGraw-Hill, Inc.

Prokopczuk, M. and Simen, C.W. (2014) The importance of the volatility risk premium for volatility forecasting. *Journal of Banking & Finance* 40: 303-320.

Putnam, G., III (1991) Investment Opportunities in Distressed Equities. In: Levine, S. (ed.) *Handbook of Turnaround and Bankruptcy Investing.* New York, NY: HarperCollins, pp. 196-207.

Puttonen, V. (1993) The ex ante profitability of index arbitrage in the new Finnish markets. *Scandinavian Journal of Management* 9(S1): 117-127.

Quintero, R.G. (1989) Acquiring the Turnaround Candidate. In: Levine, S. (ed.) *The Acquisitions Manual.* New York, NY: New York Institute of Finance, pp. 379-441.

Rad, H., Low, R.K.Y. and Faff, R. (2016) The profitability of pairs trading strategies: distance, cointegration and copula methods. *Quantitative Finance* 16(10): 1541-1558.

Rajan, A., McDermott, G. and Roy, R. (eds.) (2007) *The Structured Credit Handbook.* Hoboken, NJ: John Wiley & Sons, Inc.

Ramamurti, R. and Doh, J. (2004) Rethinking Foreign Infrastructure Investment in Developing Countries. *Journal of World Business* 39(2): 151-167.

Rao, V.K. (2011) Multiperiod Hedging using Futures: Mean Reversion and the Optimal Hedging Path. *Journal of Risk and Financial Management* 4(1): 133-161.

Rao, T. and Srivastava, S. (2012) Analyzing stock market movements using twitter sentiment analysis. In: *Proceedings of the 2012 International Conference on Advances in Social Networks Analysis and Mining (ASONAM 2012).* Washington, DC: IEEE, pp. 119-123.

Raulji, J.K. and Saini, J.R. (2016) Stop-Word Removal Algorithm and its Implementation for Sanskrit Language. *International Journal of Computer Applications* 150(2): 15-17.

Ready, R., Roussanov, N. and Ward, C. (2017) Commodity Trade and the Carry Trade: A Tale of Two Countries. *Journal of Finance* 72(6): 2629-2684.

Reddington, F.M. (1952) Review of the Principles of Life Insurance Valuations. *Journal of the Institute of Actuaries* 78(3): 286-340.

Refenes, A.N., Zapranis, A.S. and Francis, G. (1994) Stock Performance Modeling Using Neural Networks: Comparative Study with Regressive Models. *Neural Networks* 7(2): 375-388.

Rehring, C. (2012) Real Estate in a Mixed-Asset Portfolio: The Role of the Investment Horizon. *Real Estate Economics* 40(1): 65-95.

Reiss, M.F. and Phelps, T.G. (1991) Identifying a Troubled Company. In: Dinapoli, D., Sigoloff, S.C. and Cushman, R.F. (eds.) *Workouts and Turnarounds: The Handbook of Restructuring and Investing in Distressed Companies.* Homewood, IL: Business One-Irwin, pp. 7-43.

Reitano, R. (1996) Non-parallel yield curve shifts and stochastic immunization. *Journal of Portfolio Management* 22(2): 71-78.

Remolona, E.M., Wickens, M.R. and Gong, F.F. (1998) What Was the Market's View of UK Monetary Policy? Estimating Inflation Risk and Expected Inflation with Indexed Bonds. *Federal Reserve Bank of New York Staff Reports*, No. 57. Available online: https://ssrn.com/abstract=937350.

Rendleman, R.J. (1999) Duration-Based Hedging with Treasury Bond Futures. *Journal of Fixed Income* 9(1): 84-91.

Rendleman, R.J., Jones, C.P. and Latané, H.A. (1982) Empirical anomalies based on unexpected earnings and the importance of risk adjustments. *Journal of Financial Economics* 10(3): 269-287.

Reynauld, J. and Tessier, J. (1984) Risk Premiums in Futures Markets: An Empirical Investigation. *Journal of Futures Markets* 4(2): 189-211.

Rhee, S.G. and Chang, R.P. (1992) Intra-Day Arbitrage Opportunities in Foreign Exchange and Eurocurrency Markets. *Journal of Finance* 47(1): 363-379.

Ribeiro, B., Silva, C., Chen, N., Vieira, A. and das Neves, J.C. (2012) Enhanced default risk models with SVM+. *Expert Systems with Applications* 39(11): 10140-10152.

Richard, S.F. and Roll, R. (1989) Prepayments on fixed-rate mortgage-backed securities. *Journal of Portfolio Management* 15(3): 73-82.

Richards, T., Manfredo, M. and Sanders, D. (2004) Pricing weather derivatives. *American Journal of Agricultural Economics* 86(4): 1005-1017.

Richie, N., Daigler, R.T. and Gleason, K.C. (2008) The limits to stock index arbitrage: Examining S&P 500 futures and SPDRS. *Journal of Futures Markets* 28(12): 1182-1205.

Rickards, D. (2008) Global Infrastructure – A Growth Story. In: Davis, H. (ed.) *Infrastructure Finance: Trends and Techniques.* London, UK: Euromoney Books, pp. 1-47.

Rime, D., Schrimpf, A. and Syrstad, O. (2017) Segmented Money Markets and Covered Interest Parity Arbitrage. *Working Paper.* Available online: `https://ssrn.com/abstract=2879904`.

Riordan, R. and Storkenmaier, A. (2012) Latency, liquidity and price discovery. *Journal of Financial Markets* 15(4): 416-437.

Rising, J.K. and Wyner, A.J. (2012) Partial Kelly portfolios and shrinkage estimators. In: *Proceedings of the 2012 International Symposium on Information Theory (ISIT).* Washington, DC: IEEE, pp. 1618-1622.

Rödel, M. and Rothballer, C. (2012) Infrastructure as Hedge against Inflation – Fact or Fantasy? *Journal of Alternative Investments* 15(1): 110-123.

Rodríguez-González, A., García-Crespo, Á., Colomo-Palacios, R., Iglesias, F.G. and Gómez-Berbís, J.M. (2011) CAST: Using neural networks to improve trading systems based on technical analysis by means of the RSI financial indicator. *Expert Systems with Applications* 38(9): 11489-11500.

Rogers, L.C.G. and Shi, Z. (1995) The Value of an Asian Option. *Journal of Applied Probability* 32(4): 1077-1088.

Roll, R. (1996) U.S. Treasury Inflation-Indexed Bonds: The Design of a New Security. *Journal of Fixed Income* 6(3): 9-28.

Roll, R. (2004) Empirical TIPS. *Financial Analysts Journal* 60(1): 31-53.

Roll, R. and Yan, S. (2008) An explanation of the forward premium 'puzzle'. *European Financial Management* 6(2): 121-148.

Rompotis, G.G. (2011a) The performance of actively managed exchange traded funds. *Journal of Index Investing* 1(4): 53-65.

Rompotis, G.G. (2011b) Active vs. passive management: New evidence from exchange traded funds. *International Review of Applied Financial Issues and Economics* 3(1): 169-186.

Ronn, A.G. and Ronn, E.I. (1989) The Box Spread Arbitrage Conditions: Theory, Tests, and Investment Strategies. *Review of Financial Studies* 2(1): 91-108.

Rosales, E.B. and McMillan, D. (2017) Time-series and cross-sectional momentum and contrarian strategies within the commodity futures markets. *Cogent Economics & Finance* 5(1): 1339772.

Rosenberg, H. (1992) *Vulture Investors.* New York, NY: HarperCollins.

Rosenberg, B., Reid, K. and Lanstein, R. (1985) Persuasive evidence of market inefficiency. *Journal of Portfolio Management* 11(3): 9-16.

Ross, J. (2006) Exploiting spread trades. *Futures Magazine*, December 2006, pp. 34-36.

Ross, S. and Zisler, R. (1991) Risk and return in real estate. *Journal of Real Estate Finance and Economics* 4(2): 175-190.

Rothballer, C. and Kaserer, C. (2012) The Risk Profile of Infrastructure Investments: Challenging Conventional Wisdom. *Journal of Structured Finance* 18(2): 95-109.

Routledge, B., Seppi, D.J. and Spatt, C. (2000) Equilibrium forward curves for commodities. *Journal of Finance* 55(3): 1297-1338.

Rouwenhorst, K.G. (1998) International Momentum Strategies. *Journal of Finance* 53(1): 267-284.

Roy, O. and Vetterli, M. (2007) The effective rank: A measure of effective dimensionality. In: *Proceedings – EUSIPCO 2007, 15th European Signal Processing Conference.* Poznań, Poland (September 3-7), pp. 606-610.

Ruan, Y., Durresi, A. and Alfantoukh, L. (2018) Using Twitter trust network for stock market analysis. *Knowledge-Based Systems* 145: 207-218.

Ruchin, A. (2011) Can Securities Lending Transactions Substitute for Repurchase Agreement Transactions? *Banking Law Journal* 128(5): 450-480.

Ruder, S. (2017) An overview of gradient descent optimization algorithms. *Working Paper.* Available online:
https://arxiv.org/pdf/1609.04747.pdf.

Rudy, J., Dunis, C. and Laws, J. (2010) Profitable Pair Trading: A Comparison Using the S&P 100 Constituent Stocks and the 100 Most Liquid ETFs. *Working Paper.* Available online: https://ssrn.com/abstract=2272791.

Rujivan, S. and Zhu, S.P. (2012) A simplified analytical approach for pricing discretely sampled variance swaps with stochastic volatility. *Applied Mathematics Letters* 25(11): 1644-1650.

Rumelhart, D.E., Hinton, G.E. and Williams, R.J. (1986) Learning representations by back-propagating errors. *Nature* 323(6088): 533-536.

Rusnáková, M. and Šoltés, V. (2012) Long strangle strategy using barrier options and its application in hedging. *Actual Problems of Economics* 134(8): 452-465.

Rusnáková, M., Šoltés, V. and Szabo, Z.K. (2015) Short Combo Strategy Using Barrier Options and its Application in Hedging. *Procedia Economics and Finance* 32: 166-179.

Ryabkov, N. (2015) Hedge Fund Price Pressure in Convertible Bond Markets. *Working Paper.* Available online: https://ssrn.com/abstract=2539929.

Saad, E.W., Prokhorov, D.V. and Wunsch, D.C. (1998) Comparative study of stock trend prediction using time delay, recurrent and probabilistic neural networks. *IEEE Transactions on Neural Networks* 9(6): 1456-1470.

Sack, B. and Elsasser, R. (2004) Treasury Inflation-Indexed Debt: A Review of the U.S. Experience. *Federal Reserve Bank of New York, Economic Policy Review* 10(1): 47-63.

Sadka, R. (2002) The Seasonality of Momentum: Analysis of Tradability. *Working Paper.* Available online: https://ssrn.com/abstract=306371.

Sagi, J. and Seasholes, M. (2007) Firm-specific Attributes and the Cross-section of Momentum. *Journal of Financial Economics* 84(2): 389-434.

Salcedo, Y. (2004) Spreads for the fall. *Futures Magazine*, September 2004, pp. 54-57.

Saltyte-Benth, J. and Benth, F.E. (2012) A critical view on temperature modelling for application in weather derivatives markets. *Energy Economics* 34(2): 592-602.

Samuelson, P.A. (1945) The effect of interest rate increases on the banking system. *American Economic Review* 35(1): 16-27.

Samuelson, P. (1971) The "fallacy" of maximizing the geometric mean in long sequences of investing or gambling. *Proceedings of the National Academy of Sciences* 68(10): 2493-2496.

Samuelson, W. and Rosenthal, L. (1986) Price Movements as Indicators of Tender Offer Success. *Journal of Finance* 41(2): 481-499.

Samworth, R.J. (2012) Optimal weighted nearest neighbour classifiers. *Annals of Statistics* 40(5): 2733-2763.

Sanchez-Robles, B. (1998) Infrastructure Investment and Growth: Some Empirical Evidence. *Contemporary Economic Policy* 16(1): 98-108.

Saretto, A. and Goyal, A. (2009) Cross-section of option returns and volatility. *Journal of Financial Economics* 94(2): 310-326.

Sassetti, P. and Tani, M. (2006) Dynamic Asset Allocation Using Systematic Sector Rotation. *Journal of Wealth Management* 8(4): 59-70.

Satchell, S. and Scowcroft, A. (2000) A demystification of the Black-Litterman model: Managing quantitative and traditional portfolio construction. *Journal of Asset Management* 1(2): 138-150.

Savor, P. and Wilson, M. (2013) How Much Do Investors Care About Macroeconomic Risk? Evidence from Scheduled Economic Announcements. *Journal of Financial and Quantitative Analysis* 48(2): 343-375.

Sawant, R.J. (2010a) *Infrastructure Investing: Managing Risks & Rewards for Pensions, Insurance Companies & Endowments.* Hoboken, NJ: John Wiley & Sons, Inc.

Sawant, R.J. (2010b) Emerging Market Infrastructure Project Bonds: Their Risks and Returns. *Journal of Structured Finance* 15(4): 75-83.

Schaede, U. (1990) The introduction of commercial paper – a case study in the liberalisation of the Japanese financial markets. *Japan Forum* 2(2): 215-234.

Schap, K. (2005) *The complete guide to spread trading.* New York, NY: McGraw-Hill, Inc.

Schatz, H.R. (2012) The Characterization of Repurchase Agreements in the Context of the Federal Securities Laws. *St. John's Law Review* 61(2): 290-310.

Schiereck, D., Bondt, W.D. and Weber, M. (1999) Contrarian and momentum strategies in Germany. *Financial Analysts Journal* 55(6): 104-116.

Schiller, F., Seidler, G. and Wimmer, M. (2010) Temperature models for pricing weather derivatives. *Quantitative Finance* 12(3): 489-500.

Schizas, P. (2014) Active ETFs and their performance vis-à-vis passive ETFs, mutual funds, and hedge funds. *Journal of Wealth Management* 17(3): 84-98.

Schizas, P., Thomakos, D.D. and Wang, T. (2011) Pairs Trading on International ETFs. *Working Paper.* Available online: `https://ssrn.com/abstract=1958546`.

Schmidhuber, J. (2015) Deep learning in neural networks: An overview. *Neural Networks* 61: 85-117.

Schmidt, W. and Ward, I. (2002) Pricing default baskets. *Risk*, January 2002, pp. 111-114.

Schneeweis, T. and Gupta, R. (2006) Diversification benefits of managed futures. *Journal of Investment Consulting* 8(1): 53-62.

Schneider, F. and Windischbauer, U. (2008) Money laundering: some facts. *European Journal of Law and Economics* 26(3): 387-404.

Scholes, M. and Williams, J. (1977) Estimating Betas from Nonsynchronous Data. *Journal of Financial Economics* 5(3): 309-327.

Schönbucher, P.J. (2003) *Credit Derivatives Pricing Models.* Hoboken, NJ: John Wiley & Sons, Inc.

Schoutens, W. (2005) Moment swaps. *Quantitative Finance* 5(6): 525-530.

Schultz, G.M. (2016) *Investing in Mortgage-Backed and Asset-Backed Securities: Financial Modeling with R and Open Source Analytics + Website.* Hoboken, NJ: John Wiley & Sons, Inc.

Schumaker, R.P. and Chen, H. (2010) A Discrete Stock Price Prediction Engine Based on Financial News. *Computer* 43(1): 51-56.

Schwartz, E.S. (1997) The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging. *Journal of Finance* 52(3): 923-973.

Schwartz, E.S. (1998) Valuing long-term commodity assets. *Journal of Energy Finance & Development* 3(2): 85-99.

Schwartz, T.V. and Laatsch, F. (1991) Price Discovery and Risk Transfer in Stock Index Cash and Futures Markets. *Journal of Futures Markets* 11(6): 669-683.

Schwartz, E.S. and Smith, J.E. (2000) Short-term variations and long-term dynamics in commodity prices. *Management Science* 46(7): 893-911.

Schwartz, E.S. and Torous, W.N. (1989) Prepayment and the Valuation of Mortgage-Backed Securities. *Journal of Finance* 44(2): 375-392.

Schwartz, E.S. and Torous, W.N. (1992) Prepayment, Default, and the Valuation of Mortgage Pass-through Securities. *Journal of Business* 65(2): 221-239.

Schwert, G.W. (2003) Anomalies and market efficiency. In: Constantinides, G.M., Harris, M. and Stulz, R.M. (eds.) *Handbook of the Economics of Finance, Vol 1B.* (1st ed.) Amsterdam, The Netherlands: Elsevier, Chapter 15, pp. 939-974.

Sefton, J.A. and Scowcroft, A. (2005) Understanding Momentum. *Financial Analysts Journal* 61(2): 64-82.

Seiler, M.J., Webb, J.R. and Myer, F.C.N. (1999) Diversification Issues in Real Estate Investment. *Journal of Real Estate Literature* 7(2): 163-179.

Seppälä, J. (2004) The term structure of real interest rates: theory and evidence from UK index-linked bonds. *Journal of Monetary Economics* 51(7): 1509-1549.

Serban, A.F. (2010) Combining mean reversion and momentum trading strategies in foreign exchange markets. *Journal of Banking & Finance* 34(11): 2720-2727.

Seymour, B. (2008) Global Money Laundering. *Journal of Applied Security Research* 3(3-4): 373-387.

Sezer, O.B., Ozbayoglu, M. and Dogdu, E. (2017) A Deep Neural-Network Based Stock Trading System Based on Evolutionary Optimized Technical Analysis Parameters. *Procedia Computer Science* 114: 473-480.

Shackman, J.D. and Tenney, G. (2006) The Effects of Government Regulations on the Supply of Pawn Loans: Evidence from 51 Jurisdictions in the US. *Journal of Financial Services Research* 30(1): 69-91.

Shah, A. (2017) Hedging of a Portfolio of Rainfall Insurances using Rainfall Bonds and European Call Options (Bull Spread). *Working Paper.* Available online: `https://ssrn.com/abstract=2778647`.

Shah, D. and Zhang, K. (2014) Bayesian regression and Bitcoin. *Working Paper.* Available online: https://arxiv.org/pdf/1410.1231.pdf.

Shaikh, I. and Padhi, P. (2015) The implied volatility index: Is '*investor fear gauge*' or '*forward-looking*'? *Borsa Istanbul Review* 15(1): 44-52.

Shan, L., Garvin, M.J. and Kumar, R. (2010) Collar options to manage revenue risks in real toll public-private partnership transportation projects. *Construction Management and Economics* 28(10): 1057-1069.

Sharpe, W.F. (1966) Mutual Fund Performance. *Journal of Business* 39(1): 119-138.

Sharpe, W.F. (1994) The Sharpe Ratio. *Journal of Portfolio Management* 21(1): 49-58.

Sharpe, W.F. (2009) Adaptive Asset Allocation Policies. *Financial Analysts Journal* 66(3): 45-59.

Sharpe, W.F. and Perold, A.F. (1988) Dynamic Strategies for Asset Allocation. *Financial Analysts Journal* 44(1): 16-27.

Shaviro, D. (2002) Dynamic Strategies for Asset Allocation. *Chicago Journal of International Law* 3(2): 317-331.

Shen, P. (2006) Liquidity Risk Premia and Breakeven Inflation Rates. *Federal Reserve Bank of Kansas City, Economic Review* 91(2): 29-54.

Shen, P. and Corning, J. (2001) Can TIPS Help Identify Long-Term Inflation Expectations? *Federal Reserve Bank of Kansas City, Economic Review* 86(4): 61-87.

Sher, G. (2014) Cashing in for Growth: Corporate Cash Holdings as an Opportunity for Investment in Japan. *Working Paper.* Available online: https://ssrn.com/abstract=2561246.

Sherrill, D.E. and Upton, K. (2018) Actively managed ETFs vs actively managed mutual funds. *Managerial Finance* 44(3): 303-325.

Shi, H.-L., Jiang, Z.-Q. and Zhou, W.-X. (2015) Profitability of Contrarian Strategies in the Chinese Stock Market. *PLoS ONE* 10(9): e0137892.

Shiller, R.J. (1979) The Volatility of Long-Term Interest Rates and Expectations Models of the Term Structure. *Journal of Political Economy* 87(6): 1190-1219.

Shiller, R.J. and Modigliani, F. (1979) Coupon and tax effects on new and seasoned bond yields and the measurement of the cost of debt capital. *Journal of Financial Economics* 7(3): 297-318.

Shimko, D.C. (1994) Options on futures spreads: Hedging, speculation, and valuation. *Journal of Futures Markets* 14(2): 183-213.

Shin, K. and Lee, Y. (2002) A genetic algorithm application in bankruptcy prediction modeling. *Expert Systems with Applications* 23(3): 321-328.

Shiu, E.S.W. (1987) On the Fisher-Weil immunization theorem. *Insurance: Mathematics and Economics* 6(4): 259-266.

Shiu, E.S.W. (1988) Immunization of multiple liabilities. *Insurance: Mathematics and Economics* 7(4): 219-224.

Shiu, Y.-M. and Lu, T.-H. (2011) Pinpoint and Synergistic Trading Strategies of Candlesticks. *International Journal of Economics and Finance* 3(1): 234-244.

Shum, P., Hejazi, W., Haryanto, E. and Rodier, A. (2016) Intraday Share Price Volatility and Leveraged ETF Rebalancing. *Review of Finance* 20(6): 2379-2409.

Shumway, T. (2001) Forecasting Bankruptcy More Accurately: A Simple Hazard Model. *Journal of Business* 74(1): 101-104.

Siganos, A. and Chelley-Steeley, P. (2006) Momentum Profits Following Bull and Bear Markets. *Journal of Asset Management* 6(5): 381-388.

Sill, K. (1996) The Cyclical Volatility of Interest Rates. *Business Review of the Federal Reserve Bank of Philadelphia*, January/February 1996, pp. 15-29.

Simmons, E. (1954) Sales of Government Securities to Federal Reserve Banks Under Repurchase Agreements. *Journal of Finance* 9(1): 23-40.

Simon, D.P. and Campasano, J. (2014) The VIX Futures Basis: Evidence and Trading Strategies. *Journal of Derivatives* 21(3): 54-69.

Simpson, M.W. and Grossman, A. (2016) The Role of Industry Effects in Simultaneous Reversal and Momentum Patterns in One-Month Stock Returns. *Journal of Behavioral Finance* 17(4): 309-320.

Simutin, M. (2014) Cash Holdings and Mutual Fund Performance. *Review of Finance* 18(4): 1425-1464.

Sing, T.-F. and Low, S.-H.Y. (2000) The inflation-hedging characteristics of real estate and financial assets in Singapore. *Journal of Real Estate Portfolio Management* 6(4): 373-386.

Singh, Y. and Chandra, P. (2003) A class +1 sigmoidal activation functions for FFANNs. *Journal of Economic Dynamics and Control* 28(1): 183-187.

Singhal, S., Newell, G. and Nguyen, T.K. (2011) The significance and performance of infrastructure in India. *Journal of Property Research* 28(1): 15-34.

Siriopoulos, C. and Fassas, A. (2009) Implied Volatility Indices – A Review. *Working Paper.* Available online: `https://ssrn.com/abstract=1421202`.

Skelton, J.L. (1983) Banks, firms and the relative pricing of tax-exempt and taxable bonds. *Journal of Financial Economics* 12(3): 343-355.

Skiadopoulos, G. (2004) The Greek implied volatility index: construction and properties. *Applied Financial Economics* 14(16): 1187-1196.

Skiadopoulos, G., Hodges, S. and Clewlow, L. (1999) The Dynamics of the S&P 500 Implied Volatility Surface. *Review of Derivatives Research* 3(3): 263-282.

Slowinski, R. and Zopounidis, C. (1995) Application of the rough set approach to evaluation of bankruptcy risk. *Intelligent Systems in Accounting, Finance and Management* 4(1): 27-41.

Smit, H.T.J. and Trigeorgis, L. (2009) Valuing infrastructure investment: An option games approach. *California Management Review* 51(2): 82-104.

Smith, D.M. and Pantilei, V.S. (2015) Do "Dogs of the World" Bark or Bite? Evidence from Single-Country ETFs. *Journal of Investing* 24(1): 7-15.

Smith, K.V. and Shulman, D. (1976) Institutions Beware: The Performance of Equity Real Estate Investment Trusts. *Financial Analysts Journal* 32(5): 61-66.

Sollinger, A. (1994) The Triparty Is Just Beginning. *Institutional Investor* 28(1): 133-135.

Šoltés, M. (2010) Relationship of speed certificates and inverse vertical ratio call back spread option strategy. *E+M Ekonomie a Management* 13(2): 119-124.

Šoltés, V. (2011) The application of the long and short combo option strategies in the building of structured products. In: Kocourek, A. (ed.) *Proceedings of the 10th International Conference: Liberec Economic Forum 2011*. Liberec, Czech Republic: Technical University of Liberec, pp. 481-487.

Šoltés, V. and Amaitiek, O.F.S. (2010a) The Short Put Ladder Strategy and its Application in Trading and Hedging. *Club of Economics in Miskolc: Theory, Methodology, Practice* 6(2): 77-85.

Šoltés, V. and Amaitiek, O.F.S. (2010b) Inverse Vertical Ratio Put Spread Strategy and its Application in Hedging against a Price Drop. *Journal of Advanced Studies in Finance* 1(1): 100-107.

Šoltés, V. and Rusnáková, M. (2012) Long Combo strategy using barrier options and its application in hedging against a price drop. *Acta Montanistica Slovaca* 17(1): 17-32.

Šoltés, V. and Rusnáková, M. (2013) Hedging Against a Price Drop Using the Inverse Vertical Ratio Put Spread Strategy Formed by Barrier Options. *Engineering Economics* 24(1): 18-27.

Sørensen, C. (1999) Dynamic Asset Allocation and Fixed Income Management. *Journal of Financial and Quantitative Analysis* 34(4): 513-531.

Sorensen, E.H. and Burke, T. (1986) Portfolio Returns from Active Industry Group Rotation. *Financial Analysts Journal* 42(5): 43-50.

Sørensen, C. and Trolle, A.B. (2005) A General Model of Dynamic Asset Allocation with Incomplete Information and Learning. *Working paper.* Available online: `https://ssrn.com/abstract=675625`.

Sörensson, T. (1993) Two methods for valuing convertible bonds – A comparison. *Scandinavian Journal of Management* 9(S1): 129-139.

Soudijn, M.R.J. (2016) Rethinking money laundering and drug trafficking: Some implications for investigators, policy makers and researchers. *Journal of Money Laundering Control* 19(3): 298-310.

Sprenger, T.O., Tumasjan, A., Sandner, P.G. and Welpe, I.M. (2014) Tweets and trades: The information content of stock microblogs. *European Financial Management* 20(5): 926-957.

Spyrou, S.I. (2005) Index Futures Trading and Spot Price Volatility: Evidence from an Emerging Market. *Journal of Emerging Market Finance* 4(2): 151-167.

Staal, A., Corsi, M., Shores, S. and Woida, C. (2015) A Factor Approach to Smart Beta Development in Fixed Income. *Journal of Index Investing* 6(1): 98-110.

Stambaugh, R.F. (1988) The information in forward rates: Implications for models of the term structure. *Journal of Financial Economics* 21(1): 41-70.

Stanton, R. (1995) Rational Prepayment and the Valuation of Mortgage-Backed Securities. *Review of Financial Studies* 8(3): 677-708.

Statman, M., Thorley, S. and Vorkink, K. (2006) Investor Overconfidence and Trading Volume. *Review of Financial Studies* 19(4): 1531-1565.

Stattman, D. (1980) Book Values and Stock Returns. *Chicago MBA: A Journal of Selected Papers* 1980(4): 25-45.

Stefanini, F. (2006) *Investment Strategies of Hedge Funds.* Chichester, UK: John Wiley & Sons, Ltd.

Stein, J.C. (1992) Convertible bonds as backdoor equity financing. *Journal of Financial Economics* 32(1): 3-21.

Stein, J.C. (1995) Prices and Trading Volume in the Housing Market: A Model with Down-Payment Effects. *Quarterly Journal of Economics* 110(2): 379-406.

Steinert, M. and Crowe, S. (2001) Global Real Estate Investment: Characteristics, Optimal Portfolio Allocation and Future Trends. *Pacific Rim Property Research Journal* 7(4): 223-239.

Stevenson, S. (2001) Bayes-Stein Estimators and International Real Estate Asset Allocation. *Journal of Real Estate Research* 21(1/2): 89-104.

Stevenson, S. (2002) Momentum Effects and Mean Reversion in Real Estate Securities. *Journal of Real Estate Research* 23(1/2): 47-64.

Stickel, S.E. (1991) Common stock returns surrounding earnings forecast revisions: More puzzling evidence. *Accounting Review* 66(2): 402-416.

Stivers, C. and Sun, L. (2010) Cross-Sectional Return Dispersion and Time Variation in Value and Momentum Premiums. *Journal of Financial and Quantitative Analysis* 45(4): 987-1014.

Stoll, H.R. (1969) The Relationship Between Put and Call Option Prices. *Journal of Finance* 24(5): 801-824.

Stotz, O. (2016) Investment strategies and macroeconomic news announcement days. *Journal of Asset Management* 17(1): 45-56.

Stovall, S. (1996) *Sector Investing.* New York, NY: McGraw Hill, Inc.

Stroebel, J. and Taylor, J.B. (2012) Estimated Impact of the Federal Reserve's Mortgage-Backed Securities Purchase Program. *International Journal of Central Banking* 8(2): 1-42.

Stübinger, J. and Bredthauer, J. (2017) Statistical Arbitrage Pairs Trading with High-frequency Data. *International Journal of Economics and Financial Issues* 7(4): 650-662.

Stübinger, J. and Endres, S. (2017) Pairs trading with a mean-reverting jump-diffusion model on high-frequency data. *Quantitative Finance* (forthcoming). DOI: https://doi.org/10.1080/14697688.2017.1417624.

Stulz, R.M. (1996) Rethinking risk management. *Journal of Applied Corporate Finance* 9(3): 8-25.

Stulz, R.M. (2010) Credit Default Swaps and the Credit Crisis. *Journal of Economic Perspectives* 24(1): 73-92.

Su, X. (2006) Hedging basket options by using a subset of underlying assets. *Working paper.* Available online: https://www.econstor.eu/bitstream/10419/22959/1/bgse14_2006.pdf.

Su, E. and Knowles, T.W. (2010) Measuring Bond Portfolio Value at Risk and Expected Shortfall in US Treasury Market. *Asia Pacific Management Review* 15(4): 477-501.

Subha, M. and Nambi, S. (2012) Classification of stock index movement using k-Nearest Neighbours (k-NN) algorithm. *WSEAS Transactions on Information Science and Applications* 9(9): 261-270.

Subramanian, A. (2004) Option pricing on stocks in mergers and acquisitions. *Journal of Finance* 59(2): 795-829.

Suhonen, A., Lennkh, M. and Perez, F. (2017) Quantifying Backtest Overfitting in Alternative Beta Strategies. *Journal of Portfolio Management* 43(2): 90-104.

Sul, H.K., Dennis, A.R. and Yuan, L.(I). (2017) Trading on Twitter: Using Social Media Sentiment to Predict Stock Returns. *Decision Sciences* 48(3): 454-488.

Sullivan, R., Timmermann, A. and White, H. (1999) Data-snooping, technical trading rule performance, and the bootstrap. *Journal of Finance* 54(5): 1647-1691.

Summers, B.J. (1980) Negotiable Certificates of Deposit. *Federal Reserve Bank of Richmond, Economic Review* 66(4): 8-19.

Suresh, A.S. (2015) Analysis of Option Combination Strategies. *Management Insight* 11(1): 31-40.

Svec, J. and Stevenson, M. (2007) Modelling and forecasting temperature based weather derivatives. *Global Finance Journal* 18(2): 185-204.

Swank, T.A. and Root, T.H. (1995) Bonds in Default: Is Patience a Virtue? *Journal of Fixed Income* 5(1): 26-31.

Swinkels, L. (2002) International Industry Momentum. *Journal of Asset Management* 3(2): 124-141.

Swishchuk, A. and Cui, K. (2013) Weather derivatives with applications to Canadian data. *Journal of Mathematical Finance* 3(1): 81-95.

Switzer, L.N. and Jiang, H. (2010) Market Efficiency and the Risks and Returns of Dynamic Trading Strategies with Commodity Futures. In: Stanley, H.E. (ed.) *Proceedings Of The First Interdisciplinary Chess Interactions Conference.* Singapore: World Scientific Publishing, pp. 127-156.

Symeonidis, L., Prokopczuk, M., Brooks, C. and Lazar, E. (2012) Futures basis, inventory and commodity price volatility: An empirical analysis. *Economic Modelling* 29(6): 2651-2663.

Szado, E. and Schneeweis, T. (2010) Loosening Your Collar: Alternative Implementations of QQQ Collars. *Journal of Trading* 5(2): 35-56.

Szado, E. and Schneeweis, T. (2011) An Update of 'Loosening Your Collar: Alternative Implementations of QQQ Collars': Credit Crisis and Out-of-Sample Performance. *Working Paper.* Available online: `http://ssrn.com/abstract=1507991`.

Szakmary, A.C., Shen, Q. and Sharma, S.C. (2010) Trend-following trading strategies in commodity futures: A re-examination. *Journal of Banking & Finance* 34(2): 409-426.

Szakmary, A.C. and Zhou, X. (2015) Industry momentum in an earlier time: Evidence from the Cowles data. *Journal of Financial Research* 38(3): 319-347.

Tang, C.H. and Jang, S.H. (2011) Weather risk management in ski resorts: Financial hedging and Geographical diversification. *International Journal of Hospitality Management* 30(2): 301-311

Tang, H. and Xu, X.E. (2013) Solving the Return Deviation Conundrum of Leveraged Exchange-Traded Funds. *Journal of Financial and Quantitative Analysis* 48(1): 309-342.

Tavakoli, J.M. (1998) *Credit Derivatives & Synthetic Structures: A Guide to Instruments and Applications.* (2nd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Tay, F.E.H. and Cao, L. (2001) Application of support vector machines in financial time series forecasting. *Omega* 29(4): 309-317.

Taylor, C.R. (1999) Time-on-the-Market as a Sign of Quality. *Review of Economic Studies* 66(3): 555-578.

Taylor, N. (2004) Modeling discontinuous periodic conditional volatility: Evidence from the commodity futures market. *Journal of Futures Markets* 24(9): 805-834.

Taylor, N. (2016) Roll strategy efficiency in commodity futures markets. *Journal of Commodity Markets* 1(1): 14-34.

Taylor, M.P. and Allen, H. (1992) The use of technical analysis in the foreign exchange market. *Journal of International Money and Finance* 11(3): 304-314.

Teixeira, L.A. and de Oliveira, A.L.I. (2010) A method for automatic stock trading combining technical analysis and nearest neighbor classification. *Expert Systems with Applications* 37(10): 6885-6890.

Telser, L.G. (1958) Futures Trading and the Storage of Cotton and Wheat. *Journal of Political Economy* 66(3): 233-255.

The Options Institute (1995) *Options: Essential Concepts and Trading Strategies.* (2nd ed.) Chicago, IL: Richard D. Irwin, Inc.

Thibodeau, T.G. and Giliberto, S.M. (1989) Modeling Conventional Residential Mortgage Refinancing. *Journal of Real Estate Finance and Economics* 2(4): 285-299.

Thomsett, M.C. (2003) *Support and Resistance Simplified.* Columbia, MD: Marketplace Books.

Thornes, J.E. (2006) An introduction to weather and climate derivatives. *Weather* 58(5): 193-196.

Thorp, E.O. (2006) The Kelly criterion in blackjack, sports betting, and the stock market. In: Zenios, S.A. and Ziemba, W.T. (eds.) *Handbook of Asset and Liability Management: Theory and Methodology (Vol. 1).* Amsterdam, The Netherlands: Elsevier, pp. 385-428.

Thorp, E.O. and Kassouf, S.T. (1967) *Beat the Market: A Scientific Stock Market System.* New York, NY: Random House.

Till, H. (2008) Case Studies and Risk Management Lessons in Commodity Derivatives Trading. In: Geman, H. (ed.) *Risk Management in Commodity Markets: From Shipping to Agriculturals and Energy.* Chichester, UK: John Wiley & Sons, Ltd., pp. 255-291.

Till, H. and Eagleeye, J. (2017) Commodity Futures Trading Strategies: Trend-Following and Calendar Spreads. *Working Paper.* Available online: https://ssrn.com/abstract=2942340.

Tille, C., Stoffels, N. and Gorbachev, O. (2001) To What Extent Does Productivity Drive the Dollar? *Current Issues in Economics and Finance* 7(8): 1-6.

Timmermans, S.H.J.T., Schumacher, J.M. and Ponds, E.H.M. (2017) A multi-objective decision framework for lifecycle investment. *Working Paper.* Available online: http://ssrn.com/abstract=3038803.

Tinoco, M.H. and Wilson, N. (2013) Financial distress and bankruptcy prediction among listed companies using accounting, market and macroeconomic variables. *International Review of Financial Analysis* 30: 394-419.

Titman, S. and Warga, A. (1986) Risk and the Performance of Real Estate Investment Trusts: A Multiple Index Approach. *AREUEA Journal* 14(3): 414-431.

Todorov, V. (2010) Variance Risk-Premium Dynamics: The Role of Jumps. *Review of Financial Studies* 23(1): 345-383.

Toevs, A. and Jacob, D. (1986) Futures and Alternative Hedge Ratio Methodologies. *Journal of Portfolio Management* 12(3): 60-70.

Tokic, D. (2013) Crude oil futures markets: Another look into traders' positions. *Journal of Derivatives & Hedge Funds* 19(4): 321-342.

Topaloglou, N., Vladimirou, H. and Zenios, S.A. (2011) Optimizing International Portfolios with Options and Forwards. *Journal of Banking & Finance* 35(12): 3188-3201.

Torrance, M.I. (2007) The Power of Governance in Financial Relationships: Governing Tensions in Exotic Infrastructure Territory. *Growth and Change* 38(4): 671-695.

Torricelli, L. (2018) Volatility Targeting Using Delayed Diffusions. *Working Paper.* Available online: https://ssrn.com/abstract=2902063.

Trainer, F.H., Jr. (1983) The Uses of Treasury Bond Futures in Fixed Income Portfolio Management. *Financial Analysts Journal* 39(1): 27-34.

Trainor, W.J., Jr. (2010) Do Leveraged ETFs Increase Volatility? *Technology and Investment* 1(3): 215-220.

Trehan, B. (2005) Oil price shocks and inflation. *Federal Reserve Bank of San Francisco, Economic Letter*, No. 2005-28. Available online: https://www.frbsf.org/economic-research/files/el2005-28.pdf.

Trifonov, Y., Yashin, S., Koshelev, E. and Podshibyakin, D. (2011) Application of Synthetic Straddles for Equity Risk Management. In: Černák, Z. (ed.) *Materiály VII mezinárodní vědecko – praktická konference "Zprávy vědecké ideje – 2011".* Prague, Czech Republic: Education and Science.

Trifonov, Y., Yashin, S., Koshelev, E. and Podshibyakin, D. (2014) Testing the Technology of Synthetic Straddles. *Working Paper.* Available online: https://ssrn.com/abstract=2429657.

Tripathi, V. and Garg, S. (2016) A Cross-Country Analysis of Pricing Efficiency of Exchange Traded Funds. *Journal of Applied Finance* 22(3): 41-63.

Trzcinka, C. (1982) The Pricing of Tax-Exempt Bonds and the Miller Hypothesis. *Journal of Finance* 37(4): 907-923.

Tsai, C.F. and Hsiao, Y.C. (2010) Combining multiple feature selection methods for stock prediction: Union, intersection, and multi-intersection approaches. *Decision Support Systems* 50(1): 258-269.

Tsai, C., Hsu, Y. and Yen, D.C. (2014) A comparative study of classifier ensembles for bankruptcy prediction. *Applied Soft Computing* 24: 977-984.

Tse, Y. (2017) Return predictability and contrarian profits of international index futures. *Journal of Futures Markets* 38(7): 788-803.

Tsiveriotis, K. and Fernandes, C. (1998) Valuing convertible bonds with credit risk. *Journal of Fixed Income* 8(2): 95-102.

Tuckman, B. and Serrat, A. (2012) *Fixed Income Securities: Tools for Today's Markets.* (3rd ed.) Hoboken, NJ: John Wiley & Sons, Inc.

Tulchinsky, I. *et al.* (2015) *Finding Alphas: A Quantitative Approach to Building Trading Strategies.* New York, NY: John Wiley & Sons, Inc.

Turnovsky, S.J. (1989) The Term Structure of Interest Rates and the Effects of Macroeconomic Policy. *Journal of Money, Credit and Banking* 21(3): 321-347.

Tuzun, T. (2013) Are Leveraged and Inverse ETFs the New Portfolio Insurers? *Finance and Economics Discussion Series (FEDS)*, Paper No. 2013-48. Washington, DC: Board of Governors of the Federal Reserve System. Available online: https://www.federalreserve.gov/pubs/feds/2013/201348/201348pap.pdf.

Tversky, A. and Kahneman, D. (1992) Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty* 5(4): 297-323.

Uhlenbeck, G.E. and Ornstein, L.S. (1930) On the Theory of the Brownian Motion. *Physical Review* 36(5): 823-841.

Vaitonis, M. and Masteika, S. (2016) Research in high frequency trading and pairs selection algorithm with Baltic region stocks. In: Dregvaite, G. and Damasevicius, R. (eds.) *Proceedings of the 22nd International Conference on Information and Software Technologies (ICIST 2016).* Cham, Switzerland: Springer, pp. 208-217.

Van Alstyne, M. (2014) Why Bitcoin has value. *Communications of the ACM* 57(5): 30-32.

van den Goorbergh, R.W.J. (2004) *Essays on optimal hedging and investment strategies and on derivative pricing* (Ph.D. Thesis). Tilburg, The Netherlands: Tilburg University.

van den Noord, P. and André, C. (2007) Why has Core Inflation Remained so Muted in the Face of the Oil Shock? *Working Paper.* Available online: `http://dx.doi.org/10.1787/206408110285`.

Van Kervel, V. and Menkveld, A.J. (2017) High-Frequency Trading around Large Institutional Orders. *Journal of Finance* (forthcoming). Available online: `https://ssrn.com/abstract=2619686`.

van Marle, M. and Verwijmeren, P. (2017) The long and the short of convertible arbitrage: An empirical examination of arbitrageurs' holding periods. *Journal of Empirical Finance* 44: 237-249.

Van Oord, J.A. (2016) *Essays on Momentum Strategies in Finance* (Ph.D. Thesis). Rotterdam, The Netherlands: Erasmus University. Available online: `https://repub.eur.nl/pub/80036/EPS2016380F-A9789058924445.pdf`.

Vanstone, B. and Finnie, G. (2009) An empirical methodology for developing stockmarket trading systems using artificial neural networks. *Expert Systems with Applications* 36(3): 6668-6680.

Van Tassel, P. (2016) Merger Options and Risk Arbitrage. *Federal Reserve Bank of New York Staff Reports*, No. 761. Available online: `https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr761.pdf?la=en`.

Vasicek, O.A. (2015) Probability of Loss on Loan Portfolio. In: Vasicek, O.A. (ed.) *Finance, Economics and Mathematics.* Hoboken, NJ: John Wiley & Sons, Inc., Chapter 17.

Vassalou, M. and Xing, Y. (2004) Default Risk in Equity Returns. *Journal of Finance* 59(2): 831-868.

Vedenov, D.V. and Barnett, B.J. (2004) Efficiency of Weather Derivatives as Primary Crop Insurance Instruments. *Journal of Agricultural Economics* 29(3): 387-403.

Vickery, J. and Wright, J. (2010) TBA Trading and Liquidity in the Agency MBS Market. *Federal Reserve Bank of New York Staff Reports*, No. 468. Available online: `https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr468.pdf`.

Vidyamurthy, G. (2004) *Pairs Trading: Quantitative Methods and Analysis.* Hoboken, NJ: John Wiley & Sons, Inc.

Viezer, T.W. (2000) Evaluating "Within Real Estate" Diversification Strategies. *Journal of Real Estate Portfolio Management* 6(1): 75-95.

Villani, R. and Davis, C. (2006) *FLIP: How to find, fix, and sell houses for profit.* New York, NY: McGraw-Hill, Inc.

Vipul (2009) Box-spread arbitrage efficiency of Nifty index options: The Indian evidence. *Journal of Futures Markets* 29(6): 544-562.

Viswanath, P.V. (1993) Efficient Use of Information, Convergence Adjustments, and Regression Estimates of Hedge Ratios. *Journal of Futures Markets* 13(1): 43-53.

Vives, A. (1999) Pension Funds in Infrastructure Project Finance: Regulations and Instrument Design. *Journal of Structured Finance* 5(2): 37-52.

Volpert, B.S. (1991) Opportunities for Investing in Troubled Companies. In: Dinapoli, D., Sigoloff, S.C. and Cushman, R.F. (eds.) *Workouts and Turnarounds: The Handbook of Restructuring and Investing in Distressed Companies.* Homewood, IL: Business One-Irwin, pp. 514-542.

Vrugt, E.B., Bauer, R., Molenaar, R. and Steenkamp, T. (2007) Dynamic commodity trading strategies. In: Till, H. and Eagleeye, J. (eds.) *Intelligent Commodity Investing: New Strategies and Practical Insights for Informed Decision Making.* London, UK: Risk Books, Chapter 16.

Walker, J. (1999) How Big is Global Money Laundering? *Journal of Money Laundering Control* 3(1): 25-37.

Walker, M.B. (2008) The static hedging of CDO tranche correlation risk. *International Journal of Computer Mathematics* 86(6): 940-954.

Walkling, R.A. (1985) Predicting tender offer success: A logistic analysis. *Journal of Financial and Quantitative Analysis* 20(4): 461-478.

Wang, K.Q. (2005) Multifactor Evaluation of Style Rotation. *Journal of Financial and Quantitative Analysis* 40(2): 349-372.

Wang, L. (2014) Margin-Based Asset Pricing and the Determinants of the CDS Basis. *Journal of Fixed Income* 24(2): 61-78.

Wang, J., Brooks, R., Lu, X. and Holzhauer, H.M. (2017) Sector Momentum. *Journal of Investing* 26(2): 48-60.

Wang, C.-H. and Min, K.J. (2013) Electric Power Plant Valuation Based on Day-Ahead Spark Spreads. *Engineering Economist* 58(3): 157-178.

Wang, S. and Vergne, J.-P. (2017) Buzz factor or innovation potential: What explains cryptocurrencies returns? *PLoS ONE* 12(1): e0169556.

Wang, C. and Yu, M. (2004) Trading activity and price reversals in futures markets. *Journal of Banking & Finance* 28(6): 1337-1361.

Ward, D. and Griepentrog, G. (1993) Risk and Return in Defaulted Bonds. *Financial Analysts Journal* 49(3): 61-65.

Watts, R.L. (1978) Systematic 'abnormal' returns after quarterly earnings announcements. *Journal of Financial Economics* 6(2-3): 127-150.

Webb, J.R., Curcio, R.J. and Rubens, J.H. (1988) Diversification gains from including real estate in mixed-asset portfolios. *Decision Sciences* 19(2): 434-452.

Weber, B.R., Adair, A. and McGreal, S. (2008) Solutions to the five key brownfield valuation problems. *Journal of Property Investment & Finance* 26(1): 8-37.

Weber, B., Staub-Bisang, M. and Alfen, H.W. (2016) *Infrastructure as an Asset Class: Investment Strategy, Sustainability, Project Finance and PPP.* Chichester, UK: John Wiley & Sons, Ltd.

Weinert, H.L. (2007) Efficient computation for Whittaker-Henderson smoothing. *Computational Statistics & Data Analysis* 52(2): 959-974.

Weiser, S. (2003) The strategic case for commodities in portfolio diversification. *Commodities Now*, September 2003, pp. 7-11.

Weller, P.A., Friesen, G.C. and Dunham, L.M. (2009) Price trends and patterns in technical analysis: a theoretical and empirical examination. *Journal of Banking & Finance* 6(33): 1089-1100.

Wells, B. (2016) The Foreign Tax Credit War. *Brigham Young University Law Review* 2016(6): 1895-1965.

Whaley, R.E. (2000) The Investor Fear Gauge. *Journal of Portfolio Management* 26(3): 12-16.

Whaley, R.E. (2002) Return and Risk of CBOE Buy Write Monthly Index. *Journal of Derivatives* 10(2): 35-42.

Whaley, R.E. (2009) Understanding the VIX. *Journal of Portfolio Management* 35(3): 98-105.

Wheaton, W.C. (1990) Vacancy, Search, and Prices in a Housing Market Matching Model. *Journal of Political Economy* 98(6): 1270-1292.

White, L.H. (2015) The Market for Cryptocurrencies. *Cato Journal* 35(2): 383-402.

Whittaker, E.T. (1923) On a New Method of Graduations. *Proceedings of the Edinburgh Mathematical Society* 41: 63-75.

Whittaker, E.T. (1924) On the theory of graduation. *Proceedings of the Royal Society of Edinburgh* 44: 77-83.

Wilder, J.W., Jr. (1978) *New Concepts in Technical Trading Systems.* Greensboro, NC: Trend Research.

Willett, P. (2006) The Porter stemming algorithm: then and now. *Program: Electronic Library and Information Systems* 40(3): 219-223.

Wilner, R. (1996) A new tool for portfolio managers: Level, slope, and curvature durations. *Journal of Fixed Income* 6(1): 48-59.

Wilson, D.J. (2016) The Impact of Weather on Local Employment: Using Big Data on Small Places. *Federal Reserve Bank of San Francisco Working Papers Series*, No. 2016-21. Available online: `https://www.frbsf.org/economic-research/files/wp2016-21.pdf`.

Wilson, A.C., Roelofs, R., Stern, M., Stern, N. and Recht, B. (2018) The Marginal Value of Adaptive Gradient Methods in Machine Learning. *Working Paper.* Available online: `https://arxiv.org/pdf/1705.08292.pdf`.

Wilson, R.L. and Sharda, R. (1994) Bankruptcy prediction using neural networks. *Decision Support Systems* 11(5): 545-557.

Windas, T. (2007) *An Introduction to Option-Adjusted Spread Analysis.* (Miller, T. (ed.) Revised and Expanded Third Edition.) Princeton, NJ: Bloomberg Press.

Wolf, A. (1987) Optimal hedging with futures options. *Journal of Economics and Business* 39(2): 141-158.

Wolf, V. (2014) *Comparison of Markovian Price Processes and Optimality of Payoffs* (Ph.D. Thesis). Freiburg im Breisgau, Germany: Albert-Ludwigs-Universität Freiburg. Available online: `https://freidok.uni-freiburg.de/fedora/objects/freidok:9664/datastreams/FILE1/content`.

Wong, W.-K., Thompson, H.E. and Teh, K. (2011) Was There Abnormal Trading in the S&P 500 Index Options Prior to the September 11 Attacks? *Multinational Finance Journal* 15(3/4): 1-46.

Wood, J. (1997) A Simple Model for Pricing Imputation Tax Credits Under Australia's Dividend Imputation Tax System. *Pacific-Basin Finance Journal* 5(4): 465-480.

Woodard, J. and Garcia, P. (2008) Weather Derivatives, Spatial Aggregation, and Systemic Risk: Implications for Reinsurance Hedging. *Journal of Agricultural and Resource Economics* 33(1): 34-51.

Woodlock, P. and Dangol, R. (2014) Managing bankruptcy and default risk. *Journal of Corporate Accounting & Finance* 26(1): 33-38.

Woodward, G.T. (1990) The Real Thing: A Dynamic Profile of the Term Structure of Real Interest Rates and Inflation. *Journal of Business* 63(3): 373-398.

Working, H. (1953) Futures Trading and Hedging. *American Economic Review* 43(3): 314-434.

Worzala, E. and Newell, G. (1997) International real estate: A review of strategic investment issues. *Journal of Real Estate Portfolio Management* 3(2): 87-96.

Wright, R., Tekin, E., Topalli, V., McClellan, C., Dickinson, T. and Rosenfeld, R. (2017) Less Cash, Less Crime: Evidence from the Electronic Benefit Transfer Program. *Journal of Law and Economics* 60(2): 361-383.

Wu, H. (2009) Global stability analysis of a general class of discontinuous neural networks with linear growth activation functions. *Information Sciences* 179(19): 3432-3441.

Wu, L. (2003) Jumps and Dynamic Asset Allocation. *Review of Quantitative Finance and Accounting* 20(3): 207-243.

Wurstbauer, D., Lang, S., Rothballer, C. and Schäfers, W. (2016) Can common risk factors explain infrastructure equity returns? Evidence from European capital markets. *Journal of Property Research* 33(2): 97-120.

Wurstbauer, D. and Schäfers, W. (2015) Inflation hedging and protection characteristics of infrastructure and real estate assets. *Journal of Property Investment & Finance* 33(1): 19-44.

Wurtzebach, C.H., Mueller, G.R. and Machi, D. (1991) The Impact of Inflation and Vacancy on Real Estate Returns. *Journal of Real Estate Research* 6(2): 153-168.

Wystup, U. (2017) *FX Options and Structured Products.* (2nd ed.) eBook: John Wiley & Sons, Inc.

Wystup, U. and Zhou, Q. (2014) Volatility as investment – crash protection with calendar spreads of variance swaps. *Journal of Applied Operational Research* 6(4): 243-254.

Xiao, T. (2013) A simple and precise method for pricing convertible bond with credit risk. *Journal of Derivatives & Hedge Funds* 19(4): 259-277.

Xie, W., Liew, Q.R., Wu, Y. and Zou, X. (2014) Pairs Trading with Copulas. *Working Paper.* Available online: `https://ssrn.com/abstract=2383185`.

Xing, Y., Zhang, X. and Zhao, R. (2010) What Does Individual Option Volatility Smirk Tell Us About Future Equity Returns? *Journal of Financial and Quantitative Analysis* 45(3): 641-662.

Yadav, P.K. and Pope, P.F. (1990) Stock index futures arbitrage: International evidence. *Journal of Futures Markets* 10(6): 573-603.

Yadav, P.K. and Pope, P.F. (1994) Stock index futures mispricing: profit opportunities or risk premia? *Journal of Banking & Finance* 18(5): 921-953.

Yamada, S. (1999) Risk Premiums in the JGB Market and Application to Investment Strategies. *Journal of Fixed Income* 9(2): 20-41.

Yan, X. (2006) The Determinants and Implications of Mutual Fund Cash Holdings: Theory and Evidence. *Financial Management* 35(2): 67-91.

Yang, C.C., Brockett, P.L. and Wen, M.-M. (2009) Basis risk and hedging efficiency of weather derivatives. *Journal of Risk Finance* 10(5): 517-536.

Yang, Z., You, W. and Ji, G. (2011) Using partial least squares and support vector machines for bankruptcy prediction. *Expert Systems with Applications* 38(7): 8336-8342.

Yao, Y. (2012) Momentum, contrarian, and the January seasonality. *Journal of Banking & Finance* 36(10): 2757-2769.

Yao, J. and Tan, C.L. (2000) A case study on using neural networks to perform technical forecasting of forex. *Neurocomputing* 34(1-4): 79-98.

Yao, J., Tan, C.L. and Poh, H.L. (1999) Neural networks for technical analysis: a study on KLCI. *International Journal of Theoretical and Applied Finance* 2(2): 221-241.

Yared, F. and Veronesi, P. (1999) Short and Long Horizon Term and Inflation Risk Premia in the US Term Structure: Evidence from an Integrated Model for Nominal and Real Bond Prices Under Regime Shifts. *Working Paper.* Available online: https://ssrn.com/abstract=199448.

Yavas, A. and Yang, S. (1995) The Strategic Role of Listing Price in Marketing Real Estate: Theory and Evidence. *Real Estate Economics* 23(3): 347-368.

Yawitz, J.B., Maloney, K.J. and Ederington, L.H. (1985) Taxes, Default Risk, and Yield Spreads. *Journal of Finance* 40(4): 1127-1140.

Yawitz, J.B. and Marshall, W.B. (1985) The Use of Futures in Immunized Portfolios. *Journal of Portfolio Management* 11(2): 51-55.

Yeutter, C. and Dew, J.K. (1982) The Use of Futures in Bank Loans. In: Prochnow, H.V. (ed.) *Bank Credit.* New York, NY: Harper and Row.

Yim, H.L., Lee, S.H., Yoo, S.K. and Kim, J.J. (2011) A zero-cost collar option applied to materials procurement contracts to reduce price fluctuation risks in construction. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering* 5(12): 1769-1774.

Yo, S.W. (2001) Index Futures Trading and Spot Price Volatility. *Applied Economics Letters* 8(3): 183-186.

Yoshikawa, D. (2017) An Entropic Approach for Pair Trading. *Entropy* 19(7): 320.

Youbi, F., Pindza, E. and Maré, E. (2017) A Comparative Study of Spectral Methods for Valuing Financial Options. *Applied Mathematics & Information Sciences* 11(3): 939-950.

Young, M. and Graff, R.A. (1996) Systematic Behavior in Real Estate Investment Risk: Performance Persistence in NCREIF Returns. *Journal of Real Estate Research* 12(3): 369-381.

Ysmailov, B. (2017) Interest Rates, Cash and Short-Term Investments. *Working Paper.* Available online: http://www.fmaconferences.org/Boston/Interest_Rates_Cash_and_ShortTermInv.pdf.

Yu, L., Wang, S. and Lai, K.K. (2005) Mining Stock Market Tendency Using GA-Based Support Vector Machines. In: Deng, X. and Ye, Y. (eds.) *Internet and Network Economics. WINE 2005. Lecture Notes in Computer Science, Vol. 3828.* Berlin, Germany: Springer, pp. 336-345.

Yu, S. and Webb, G. (2014) The Profitability of Pairs Trading Strategies Based on ETFs. *Working Paper.* Available online: http://swfa2015.uno.edu/B_Asset_Pricing_III/paper_196.pdf.

Zabolotnyuk, Y., Jones, R. and Veld, C. (2010) An empirical comparison of convertible bond valuation models. *Financial Management* 39(2): 675-706.

Zakamulin, V. (2014a) The Real-Life Performance of Market Timing with Moving Average and Time-Series Momentum Rules. *Journal of Asset Management* 15(4): 261-278.

Zakamulin, V. (2014b) Dynamic Asset Allocation Strategies Based on Unexpected Volatility. *Journal of Alternative Investments* 16(4): 37-50.

Zakamulin, V. (2015) A Comprehensive Look at the Empirical Performance of Moving Average Trading Strategies. *Working Paper.* Available online: https://ssrn.com/abstract=2677212.

Zapranis, A. and Alexandridis, A. (2008) Modelling the temperature time-dependent speed of mean reversion in the context of weather derivatives pricing. *Applied Mathematical Finance* 15(3-4): 355-386.

Zapranis, A. and Alexandridis, A. (2009) Weather derivatives pricing: modeling the seasonal residual variance of an Ornstein-Uhlenbeck temperature process with neural networks. *Neurocomputing* 73(1-3): 37-48.

Zapranis, A. and Tsinaslanidis, P.E. (2012) Identifying and evaluating horizontal support and resistance levels: an empirical study on US stock markets. *Applied Financial Economics* 22(19): 1571-1585.

Zaremba, A. (2014) A Performance Evaluation Model for Global Macro Funds. *International Journal of Finance & Banking Studies* 3(1): 161-171.

Zeng, L. (2000) Pricing weather derivatives. *Journal of Risk Finance* 1(3): 72-78.

Zeng, Z. and Lee, C.G. (2014) Pairs trading: Optimal thresholds and profitability. *Quantitative Finance* 14(11): 1881-1893.

Zhang, C. (2015) Using Excel's Data Table and Chart Tools Effectively in Finance Courses. *Journal of Accounting and Finance* 15(7): 79-93.

Zhang, L. (2005) The Value Premium. *Journal of Finance* 60(1): 67-103.

Zhang, L. (2014) A closed-form pricing formula for variance swaps with mean-reverting Gaussian volatility. *ANZIAM Journal* 55(4): 362-382.

Zhang, X.F. (2006) Information Uncertainty and Stock Returns. *Journal of Finance* 61(1): 105-136.

Zhang, J.Z., Fargher, N.L. and Hou, W. (2018) Do Banks Audited by Specialists Engage in Less Real Activities Management? Evidence from Repurchase Agreements. *AUDITING: A Journal of Practice & Theory* (forthcoming). DOI: `https://doi.org/10.2308/ajpt-52017`.

Zhang, X., Fuehres, H. and Gloor, P.A. (2011) Predicting Stock Market Indicators Through Twitter "I hope it is not as bad as I fear". *Procedia – Social and Behavioral Sciences* 26: 55-62.

Zhang, J.E., Shu, J. and Brenner, M. (2010) The new market for volatility trading. *Journal of Futures Markets* 30(9): 809-833.

Zhang, J.E. and Xiang, Y. (2008) The implied volatility smirk. *Quantitative Finance* 8(3): 263-284.

Zhang, J.E. and Zhu, Y. (2006) VIX futures. *Journal of Futures Markets* 26(6): 521-531.

Zheng, W. and Kwok, Y.K. (2014) Closed form pricing formulas for discretely sampled generalized variance swaps. *Mathematical Finance* 24(4): 855-881.

Zheng, H., Thomas, L.C. and Allen, D.E. (2003) The Duration Derby: A Comparison of Duration Strategies in Asset Liability Management. *Journal of Bond Trading and Management* 1(4): 371-380.

Zhou, L. (2013) Performance of corporate bankruptcy prediction models on imbalanced dataset: The effect of sampling methods. *Knowledge-Based Systems* 41: 16-25.

Zhou, L., Yao, S., Wang, J. and Ou, J. (2016) Global financial crisis and China's pawnbroking industry. *Journal of Chinese Economic and Business Studies* 14(2): 151-164.

Zhu, H. (2006) An Empirical Comparison of Credit Spreads between the Bond Market and the Credit Default Swap Market. *Journal of Financial Services Research* 29(3): 211-235.

Zmijewski, M.E. (1984) Methodological Issues Related to the Estimation of Financial Distress Prediction Models. *Journal of Accounting Research* 22: 59-82.

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 assets 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 nonlinear 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 security'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 different 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} ($i = 1, \dots, N$, $A = 1, \dots, K$, 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 security 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.), energy (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 ($i = 1, \dots, N$), 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 transform 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 $p_1, \dots, p_k$.

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 ($i = 1, \dots, N$) 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 ($i = 1, \dots, N$) 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 ($i = 1, \dots, N$).

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 $t_1, t_2, \dots$, 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 securities) 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 ($i = 1, \dots, N$), 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 ($i = 1, \dots, N$) 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 ($i = 1, \dots, N$).

$\prod_{i=1}^{N} x_i$ product of N values x_i ($i = 1, \dots, N$).

$A|_{B=b}$ (or $A|_b$)   the value of A when some quantity B it implicitly depends on (usually evident from the context) takes value b.

$f(x) \rightarrow \min$ (max)   minimizing (maximizing) $f(x)$ w.r.t. x (where x can, e.g., be an N-vector x_i, $i = 1, \dots, N$).

$\text{argmax}_z\, f(z)$ 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 ($i = 1, \dots, N$) 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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