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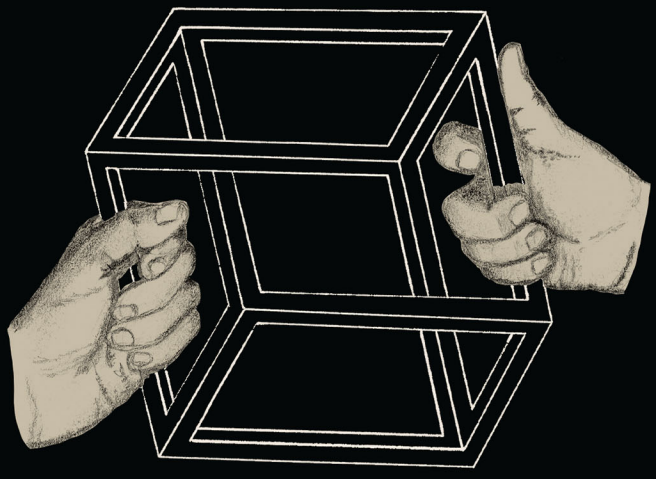
INSIDE THE BLACK BOX

A SIMPLE GUIDE TO SYSTEMATIC INVESTING



rishi k narang

FOREWORD BY PETE MULLER

THIRD EDITION

Inside the Black Box

Third Edition

Inside the Black Box

A Simple Guide to Systematic Investing

Third Edition

RISHI K NARANG

WILEY

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Foreword

In 1992, I joined a large bank with the aim of becoming a quant trader. I had spent the previous seven years working for a financial consulting firm, and when that started to get a little boring, learning to play poker competitively. I had read every paper I could find about exploiting market inefficiencies, and I thought my background gave me a reasonable chance at being successful. And I was, thanks to a combination of luck, hard work, and some fantastic colleagues.

I wish that at the time I started PDT, I had had a book like Rishi's. It would have given me a lot of ideas and saved me a lot of time and mistakes. But let me be clear. Reading *Inside the Black Box* will not teach you how to make money using quantitative techniques in financial markets. Few people have figured out how to do that, and those of us who have are understandably reluctant to share our secrets. On the other hand, this book will provide helpful, accurate information about the different approaches that quantitative traders use, and the myriad of disciplines they need to understand to succeed. For someone new to the field, or looking to invest quantitatively, Rishi has provided a great guidebook.

Most of the people we hire at PDT have backgrounds in physics, mathematics, engineering, or computer science. We provide a finance reading list to get them up to speed in their new domain. The previous edition of Rishi's book has been on that list, and so will this version, which includes great updates in the sections on portfolio construction, risk management, and research.

As a long-term allocator to smaller quant funds, Rishi Narang has seen first-hand a lot of the mistakes quants make, and the challenges they face. *Inside the Black Box* is clearly written, provides a thorough overview of all things quant, and dispassionately presents different perspectives on controversial issues. I hope you enjoy it!

Pete Muller
Founder and CEO, PDT Partners

Preface to the Third Edition

It is hard to believe that it has been 15 years since I wrote the first edition of *Inside the Black Box*. I never could have guessed it would end up being used by quant funds as a training manual, nor as a textbook in grad school classes on quant finance. I wrote that first edition more or less in anger, in the wake of the August 2007 quant meltdown. Investors, reporters, and regulators were asking stupid questions and making stupid statements and generalizations. I was complaining to Steve Drobny at his home in Manhattan Beach about how unfathomable it is that people couldn't understand what quants do, because it's so obvious and transparent. He retorted, "If it's that easy, write a book." All it took was a brief hesitation in response, and Steve had already punched out an email to Wiley Finance, publisher of his legendary *Inside the House of Money*, on his Blackberry, insisting that they publish my then-nonexistent (and not-yet-conceived) book.

About four years later, I reluctantly undertook to update the book to address another annoying, widely misunderstood, but ultimately straightforward topic—high frequency trading. I also updated and upgraded many other aspects of the book, and, in my mind, my work on the topic of explaining systematic investing in plain English was probably done. The principles and concepts remained valid and relevant, so while there might be this minor advancement or that new methodology to solve an extant problem, I saw no need to put out another edition.

So much has changed since then. We've had Brexit, a couple of highly contentious U.S. elections, a global pandemic, continued acts of terrorism and armed conflicts in several parts of the world. We've had a plethora of natural disasters, most of which are spurred by climate change—massive hurricanes, bomb cyclones, atmospheric rivers. We've also had the development of crypto-currencies, decentralized finance, non-fungible tokens, and Web3. A new wave of speculators came (and has now gone?) whose aims seem to have been not-entirely economic in nature—they live by mantras-as-acronyms, such as FOMO, YOLO, and HODL. We've had a few highlights too: the 2015 Paris Accord, the rapid development of a new kind of vaccine and other treatments to ameliorate a pandemic that very much remains with us, the creation of a whole new category of investable assets (crypto-currencies), and the advent of Large Language Models. Much else

has changed and happened, but all these events were directly relevant to capital markets and the investors who participate in them.

More to the point, the quant investing industry, too, has had an eventful decade. Acceptance of this approach to investing as a valid and important one is now widespread, and assets under management among quants have grown significantly. Certain business models have become significantly favored by many investors, which has had a direct impact on the competitive landscape of practitioners in the space. And beyond business considerations, the work itself has evolved significantly. Machine-learning techniques went from fringe and cutting edge to ubiquitous. Alternative datasets were also very new a decade ago, and now those too are everywhere. The asset classes and geographies accessible to and traded by quants have expanded dramatically. While none of this really changes the core concepts presented even in the first edition, there was enough to do that I felt it was time to update.

The basic layout of this book is the same as that of the second edition's. Part One (Chapters 1 and 2) contains some introductory material and an overview of the structure of systematic investing strategies. Part Two (Chapters 3–9) contains an explication of the various aspects of that structure. Part Three (Chapters 10–12) presents a practical guide to investing in quantitative strategies. Part Four (Chapters 13–15) contains an explanation of high-frequency trading. And again, we close in Chapter 16 with a look at some interesting current and future topics in this space of innovation and evolution. We have moved the discussion of criticisms of high-frequency trading to an appendix, as this was far more topical in the few years following the financial crisis than it has been since.

And as much as has changed and happened, far more fundamentally, things remain very much the same. Quant investing remains different from traditional, discretionary approaches largely in a different model, focusing on *how* to go about investing, rather than on *what* is being done. The ideas utilized by quants remain mostly driven by an economic rationale that would make total sense to most people. Quants continue to have only modestly-better-than-random odds of success on any given forecast or position and continue to rely on diversification of bets (either across many positions at once, or by taking many bets over time, or both). They still compete with each other to sniff out inefficiencies created by various market participants' varying utility functions or suboptimal behaviors. The bulk of the interesting work in this industry continues to be performed by humans, largely in the framework of scientific research. Egos continue to be negatively associated with the probability of success.

As before, my goal is to explain things in terms as plain as possible. If you have a basic understanding of capital markets, you should be able to understand this book. And, in turn, hopefully, you will develop a better understanding of a corner of the investment management industry that, undoubtedly, will only continue to gain prominence and market share.

Acknowledgments

I want to start by thanking Steve Drobny, without whom I would never have written a book at all. He has been a great friend, and he's a great human being.

I also want to thank my publisher, Wiley Finance, and especially Bill Falloon, Vitusha Rameshan, and Purvi Patel. Wiley took a chance on me some 15 years ago, when I was no one they knew about, solely on the back of Steve's say-so. I thank Susan Dunsmore for her excellent copy-editing and catching so many of my mistakes.

For their help with large portions of this edition, I am grateful to my colleagues Dave Demers and Tim Long. I am also thankful for Samantha Broussard-Wilson's help with updating industry data. Julie Wilson, my colleague since the first day of T2AM's existence, has my gratitude for her partnership all these long years.

Chapter 6 greatly benefited from the input of Stephen Boyd and Kasper Johansson. Kasper also kindly and deftly created the new optimization exhibits in Chapter 6, while on holiday. Mani Mahjouri and Brian Englebert were extremely helpful with Chapter 8—it ended up being a much bigger lift than I anticipated, but they made it possible. I am also thankful to Matthew Rothman, who's been a friend for more than 16 years, and who was an excellent sounding board for Chapter 16. I also want to thank Kevin Plominski for his help with some data on the industry generally.

On a personal note, I want to thank Miko Lim for his photographs. I also want to express how grateful I am to my son, Solomon Narang. He was only three years old when the second edition came out, and he'll be 14 when this one does. I am so proud of you, my little man. Last, and certainly not least, I want to say a huge thank you to Ali Menoutis, who has been a wonderful partner and teacher these past three years.

I could not have known what doors would open and what amazing connections I would make as a result of the publication of *ItBB*. It is clear that it changed my life very significantly. I want to just say aloud how grateful I am for all the wonderful friends I have been lucky to make and experiences I have been lucky to have as a result.

Inside the Black Box

PART

One

The Quant Universe

CHAPTER 1

Why Does Quant Trading Matter?

Look into their minds, at what wise men do and don't.
—Marcus Aurelius, *Meditations*

John is a quant trader running a mid-sized hedge fund. He completed an undergraduate degree in mathematics and computer science at a top school in the early 1990s. John immediately started working on Wall Street trading desks, eager to capitalize on his quantitative background. After seven years on the Street in various quant-oriented roles, John decided to start his own hedge fund. With partners handling business and operations, John was able to create a quant strategy that recently was trading over $1.5 billion per day in equity volume. More relevant to his investors, the strategy made money on 60 percent of days and 85 percent of months—a rather impressive accomplishment.

Despite trading billions of dollars of stock every day, there is no shouting at John's hedge fund, no orders being given over the phone, and no drama in the air; in fact, the only sign that there is any trading going on at all is the large flat-screen television in John's office that shows the strategy's performance throughout the day and its trading volume. John can't give you a fantastically interesting story about why his strategy is long this stock or short that one. While he is monitoring his universe of thousands of stocks for events that might require intervention, for the most part he lets the automated trading strategy do the hard work. What John monitors quite carefully, however, is the health of his strategy and the market environment's impact on it. He is aggressive about conducting research on an ongoing basis to adjust his models for changes in the market that would impact him.

Across from John sits Mark, a recently hired partner of the fund who is researching high-frequency trading. Unlike the firm's first strategy, which

only makes money on 6 out of 10 days, the high-frequency efforts Mark and John are working on target a much more ambitious task: looking for smaller opportunities that can make money every day. Mark's first attempt at high-frequency strategies already makes money nearly 95 percent of the time. In fact, their target for this high-frequency business is even loftier: They want to replicate the success of those firms whose trading strategies make money every hour, maybe even every minute, of every day. Such high-frequency strategies can't accommodate large investments, because the opportunities they find are small, fleeting. The technology required to support such an endeavor is also incredibly expensive, not only to build, but also to maintain. Nonetheless, they are highly attractive for whatever capital they can accommodate. Within their high-frequency trading business, John and Mark expect their strategy to generate returns of about 200 percent a year, possibly much more.

Per the FT, quoting Hedge Fund Research's report, quants managed over $900 billion in assets at the end of October 2017,[1] nearly double the level from 2010, with continued inflows since. Aurum put the number a bit under half that amount in 2022, but even $445 billion is a significant sum, representing about 14 percent of the total assets under management they estimated are in hedge funds (and making quant the second largest category of hedge funds).[2] It is clear that quants are substantial players in the market, and that they're not only here to stay, but growing.

Not all quants are successful, however. It seems that once every decade or so, quant traders cause—or at least are perceived to cause—markets to move dramatically because of their failures, though we have only about four datapoints, the most recent from 2010, at which to point. The most obvious instance is, of course, Long Term Capital Management (LTCM), which nearly (but for the intervention of Federal Reserve banking officials and a consortium of Wall Street banks) brought the financial world to its knees. Although the world markets survived, LTCM itself was not as lucky. The firm, which averaged 30 percent returns after fees for four years, lost nearly 100 percent of its capital in the debacle of August–October 1998 and left many investors both skeptical and afraid of quant traders. Never mind that it is debatable whether this was a quant trading failure or a failure of human judgment in risk management, nor that it's questionable whether LTCM was even a quant trading firm at all. It was staffed by PhDs and Nobel Prize-winning economists, and that was enough to cast it as a quant trading outfit, and to make all quants "guilty by association."

Not only have quants been widely panned because of LTCM, but they have also been blamed (probably unfairly) for the crash of 1987 and (quite fairly) for the eponymous quant liquidation of 2007, the latter having severely impacted many quant shops. Even some of the largest names

in quant trading suffered through August 2007's quant liquidation. For instance, Goldman Sachs' largely quantitative Global Alpha Fund was down an estimated 40 percent in 2007 after posting a 6 percent loss in 2006.[3] In less than a week during August 2007, many quant traders lost between 10 and 40 percent in a few days, though some of them rebounded strongly for the remainder of the month.

A best-selling nonfiction book by a former *Wall Street Journal* reporter even attempted to cast the blame for the massive financial crisis that came to a head in 2008 on quant trading. There were gaps in his logic large enough to drive an 18-wheeler through, but the popular perception of quants has never been positive. And this is all before high-frequency trading (HFT) came into the public consciousness in 2010, after the "Flash Crash" on May 10th of that year. Ever since then, various corners of the investment and trading world have tried very hard to assert that quants (this time, in the form of HFTs) are responsible for increased market volatility, instability in the capital markets, market manipulation, front-running, and many other evils. We will look into HFT and the claims leveled against it in greater detail in Chapter 16, but any quick search of the internet will confirm that quant trading and HFT have left the near-total obscurity they enjoyed for decades and entered the mainstream's thoughts on a regular basis.

There was also the Flash Crash on May 6, 2010, during which the U.S. stock market lost some 7 percent in a mere 15 minutes, with about $1 trillion in market capitalization vanishing. Eight large cap companies, including Accenture and Exelon, fell to $0.01 per share—an exceedingly low price. Twenty minutes later, most of the loss had been recovered. Quants were widely blamed for the incident, most notably by Michael Lewis, in *Flash Boys*.

More recently, but less significantly, Bloomberg published an article on November 30, 2023, entitled, "Oil's Wild Ride Is Driven by a Disruptive Band of Bot Traders," which claimed that the trend-following quant strategies add to volatility (and point only to oil prices increasing due to such pressure) by engaging in what humans have always done—follow trends. I am certain that there were no algorithms behind the bubble in tulips in Holland, nor in the roaring 1920s in the U.S. But, yes, let's blame the quants. As an apropos error in reporting, the authors quote a quant from Cayler Capital. While they correctly categorize Cayler as a Commodity Trading Advisor (CTA, for short, and a type of institution that is distinguished only by its trading of futures on behalf of clients—not by being systematic in so doing), they lump his firm in with trend followers. Even more ironically, this article merely recounts an anecdote in which the portfolio manager decided not to intervene in his models, which happened to be positioned correctly for the Russian invasion of Ukraine, vis-à-vis oil prices.[4]

Leaving aside the spectacular successes and failures of quant trading, and all the ills for which quant trading is blamed by some, there is no doubt that quants cast an enormous shadow over the capital markets virtually every trading day. Across U.S. equity markets, a significant, and rapidly growing, proportion of all trading is done through algorithmic execution, one footprint of quant strategies. (*Algorithmic execution* is the use of computer software to manage and "work" an investor's buy and sell orders in electronic markets.) Although this automated execution technology is not the exclusive domain of quant strategies—any trade that needs to be done, whether by an index fund or a discretionary macro trader, can be worked using execution algorithms—certainly a substantial portion of all algorithmic trades are done by quants. Furthermore, quants were both the inventors of, and primary innovators of, algorithmic trading engines. A mere five such quant traders account for about 1 billion shares of volume *per day*, in aggregate, in the United States alone. It is worth noting that not one of these is well known to the broader investing public, even now, after all the press surrounding high-frequency trading. As of 2017, algorithmic trading—which to be clear, represents only the execution of trades, not whether the determinant of that investment decision came via a human utilizing a trading algorithm or a systematic investing strategy utilizing potentially the same kind of algorithm—accounted for about 70 percent of equity trading, 50 percent of futures trading, 40 percent of options trading, 25 percent of foreign exchange trading, and almost 10 percent of fixed income trading.[5]

It is clear that the magnitude of quant trading among hedge funds is substantial. In 2021, SigTech estimated that about 22 percent of the world's hedge funds were entirely systematic. That portion will not likely be declining. Furthermore, another of their surveys from early 2022 indicated that about 95 percent of respondents believed that even discretionary hedge fund managers are increasing their use of systematic tools in their investment processes. While this is hardly an unbiased source, their observations are in line with my own observations of the industry.

Hedge funds are private investment pools that are accessible only to sophisticated, wealthy individual or institutional clients. They can pursue virtually any investment mandate one can dream up, and they are allowed to keep a portion of the profits they generate for their clients. But this is only one of several arenas in which quant trading is widespread. Proprietary trading desks at the various banks, boutique proprietary trading firms, and various "multi-strategy" hedge fund managers who utilize quantitative trading for a portion of their overall business each contribute to a much larger estimate of the size of the quant trading universe.

With such size and extremes of success and failure, it is not surprising that quants take their share of headlines in the financial press. And though

most press coverage of quants seems to be markedly negative, this is not always the case. In fact, not only have many quant funds been praised for their steady returns (a hallmark of their disciplined implementation process), but some experts have even argued that the existence of successful quant strategies improves the marketplace for all investors, regardless of their style. For instance, Reto Francioni (chief executive of Deutsche Börse AG, which runs the Frankfurt Stock Exchange) said in a speech that algorithmic trading "benefits all market participants through positive effects on liquidity." Francioni went on to reference a recent academic study showing "a positive causal relationship between algo trading and liquidity."[6] Indeed, this is almost guaranteed to be true. Quant traders, using execution algorithms (hence, "algo trading"), typically slice their orders into many small pieces to improve both the cost and efficiency of the execution process. As mentioned before, although originally developed by quant funds, these algorithms have been adopted by the broader investment community. By placing many small orders, other investors who might have different views or needs can also get their own executions improved.

Quants typically make markets more efficient for other participants by providing liquidity when other traders' needs cause a temporary imbalance in the supply and demand for a security. These imbalances are known as "inefficiencies," after the economic concept of "efficient markets." True inefficiencies (such as an index's price being different from the weighted basket of the constituents of the same index) represent rare, fleeting opportunities for riskless profit. But riskless profit, or arbitrage, is not the only—or even primary—way in which quants improve efficiency. The main inefficiencies quants eliminate (and, thereby, profit from) are not absolute and unassailable, but rather are probabilistic and require risk-taking.

A classic example of this is a strategy called *statistical arbitrage*, and a classic statistical arbitrage example is a *pairs trade*. Imagine two stocks with similar market capitalizations from the same industry and with similar business models and financial status. For whatever reason, Company A is included in a major market index, an index that many large index funds are tracking. Meanwhile, Company B is not included in any major index. It is likely that Company A's stock will subsequently outperform shares of Company B simply due to a greater demand for the shares of Company A from index funds, which are compelled to buy this new constituent in order to track the index. This outperformance will in turn cause a higher P/E multiple on Company A than on Company B, which is a subtle kind of inefficiency. After all, nothing in the fundamentals has changed—only the nature of supply and demand for the common shares. Statistical arbitrageurs may step in to sell shares of Company A to those who wish to buy, and buy shares of Company B from those looking to sell, thereby preventing the divergence

between these two fundamentally similar companies from getting out of hand and improving efficiency in market pricing. Let us not be naïve: they improve efficiency not out of altruism, but because these strategies are set up to profit if indeed a convergence occurs between Companies A and B.

This is not to say that quants are the only players who attempt to profit by removing market inefficiencies. Indeed, it is likely that any alpha-oriented trader is seeking similar, or at least analogous, sorts of dislocations as sources of profit. And, of course, there are times, such as August 2007, when quants actually cause the markets to be temporarily *less* efficient. Nonetheless, especially in smaller, less liquid, and more neglected stocks, statistical arbitrage players are often major providers of market liquidity and help establish efficient price discovery for all market participants.

So, what can we learn from a quant's approach to markets? The three answers that follow represent important lessons that quants can teach us—lessons that can be applied by any investment manager.

1.1 THE BENEFIT OF DEEP THOUGHT

According to James Simons, the founder of the legendary Renaissance Technologies, one of the greatest advantages quants bring to the investment process is their systematic approach to problem solving. As Dr. Simons puts it, "The advantage scientists bring into the game is less their mathematical or computational skills than their ability to think scientifically."[7]

The first reason it is useful to study quants is that they are forced to think deeply about many aspects of their strategy that are taken for granted by non-quant investors. Why does this happen? Computers are obviously powerful tools, but without absolutely precise instruction, they can achieve nothing. So, to make a computer implement a "black box trading strategy" requires an enormous amount of effort on the part of the developer. You can't tell a computer to "find cheap stocks." You have to specify what *find* means, what *cheap* means, and what *stocks* are. For example, *finding* might involve searching a database with information about stocks and then ranking the stocks within a market sector (based on some classification of stocks into sectors). *Cheap* might mean P/E ratios, though one must specify both the metric of cheapness and what level will be considered cheap. As such, the quant can build his system so that cheapness is indicated by a 10 P/E or by those P/Es that rank in the bottom decile of those in their sector. And *stocks*, the universe of the model, might be all U.S. stocks, all global stocks, all large cap stocks in Europe, or whatever other group the quant wants to trade.

All this defining leads to a lot of deep thought about exactly what one's strategy is, how to implement it, and so on. In the preceding example, the

quant doesn't have to choose to rank stocks within their sectors. Instead, stocks can be compared to their industry peers, to the market overall, or to any other reasonable group. But the point is that the quant is encouraged to be intentional about these decisions by virtue of the fact that the computer will not fill in any of these blanks on its own.

The benefit of this should be self-evident. Deep thought is usually a good thing. Even better, this kind of detailed and rigorous working out of how to divide and conquer the problem of conceptualizing, defining, and implementing an investment strategy is useful to quants and discretionary traders alike. These benefits largely accrue from thoroughness, which is generally held to be a key ingredient to investment or trading success. By contrast, many (though certainly not all) discretionary traders, because they are not forced to be so precise in the specification of their strategy and its implementation, seem to take a great many decisions in an *ad hoc* manner. I have been in countless meetings with discretionary traders who, when I asked them how they decided on the sizes of their positions, responded with variations on the theme of, "Whatever seemed reasonable." This is by no means a damnation of discretionary investment styles. I merely point out that precision and deep thought about many details, in addition to the bigger-picture aspects of a strategy, can be a good thing, and this lesson can be learned from quants.

1.2 THE MEASUREMENT AND MISMEASUREMENT OF RISK

As mentioned earlier in this chapter, the history of LTCM is a lesson in the dangers of mismeasuring risk. Quants are naturally predisposed toward conducting all sorts of measurements, including of risk exposure. This activity itself has potential benefits and downsides. On the plus side, there is a certain intentionality of risk-taking that a well-conceived quant strategy encourages. Rather than accepting accidental risks, the disciplined quant attempts to isolate exactly what his edge is and focus his risk-taking on those areas that isolate this edge. To root out these risks, the quant must first have an idea of what these risks are and how to measure them. For example, most quant equity traders, recognizing that they do not have sufficient capabilities in forecasting the direction of the market itself, measure their exposure to the market (using their net dollar or beta exposure, commonly) and actively seek to limit this exposure to a trivially small level by balancing their long portfolios against their short portfolios. On the other hand, there are very valid concerns about false precision, measurement error, and incorrect sets of assumptions that can plague attempts to measure risk and manage it quantitatively.

All the blowups we have mentioned, and most of those we haven't, stem in one way or another from this over-reliance on flawed risk measurement techniques. In the case of LTCM, for example, historical data showed that certain scenarios were likely, others unlikely, and still others had simply never occurred. At that time, most market participants did not expect that a country of Russia's importance, with a substantial supply of nuclear weapons and natural resources, would go bankrupt. Nothing like this had ever happened in modern history. Nevertheless, Russia indeed defaulted on its debt in the summer of 1998, sending the world's markets into a frenzy and rendering useless any measurement of risk. The naïve over-reliance on quantitative measures of risk, in this case, led to the near-collapse of the financial markets in the autumn of 1998. But for a rescue orchestrated by the U.S. government and agreed on by most of the powerhouse banks on Wall Street, we would have seen a very different path unfold for the capital markets and all aspects of financial life.

Indeed, the credit debacle that began to overwhelm markets in 2007 and 2008, too, was likely avoidable. Banks relied on credit risk models that simply were unable to capture the risks correctly. In many cases, they seem to have done so knowingly, because it enabled them to pursue outsized short-term profits (and, of course, bonuses for themselves). It should be said that most of these mismeasurements could have been avoided, or at least the resulting problems mitigated, by the application of better judgment on the part of the practitioners who relied on them. Just as one cannot justifiably blame weather-forecasting models for the way that New Orleans was impacted by Hurricane Katrina in 2005, it would not make sense to blame quantitative risk models for the failures of those who created and use them. Traders can benefit from engaging in the exercise of understanding and measuring risk, so long as they are not seduced into taking ill-advised actions as a result.

1.3 DISCIPLINED IMPLEMENTATION

Perhaps the most obvious lesson we can learn from quants comes from the discipline inherent to their approach. Upon designing and rigorously testing a strategy that makes economic sense and seems to work, a properly run quant shop simply tends to let the models run without unnecessary, arbitrary interference. In many areas of life, from sports to science, the human ability to extrapolate, infer, assume, create, and learn from the past is beneficial in the planning stages of an activity. But execution of the resulting plan is also critical, and it is here that humans frequently are found to be lacking. A significant driver of failure is a lack of discipline.